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AIR TRAFFIC CONTROL EXPERIMENTATION AND EVALUATION WITH THE NAS--ETC(U)
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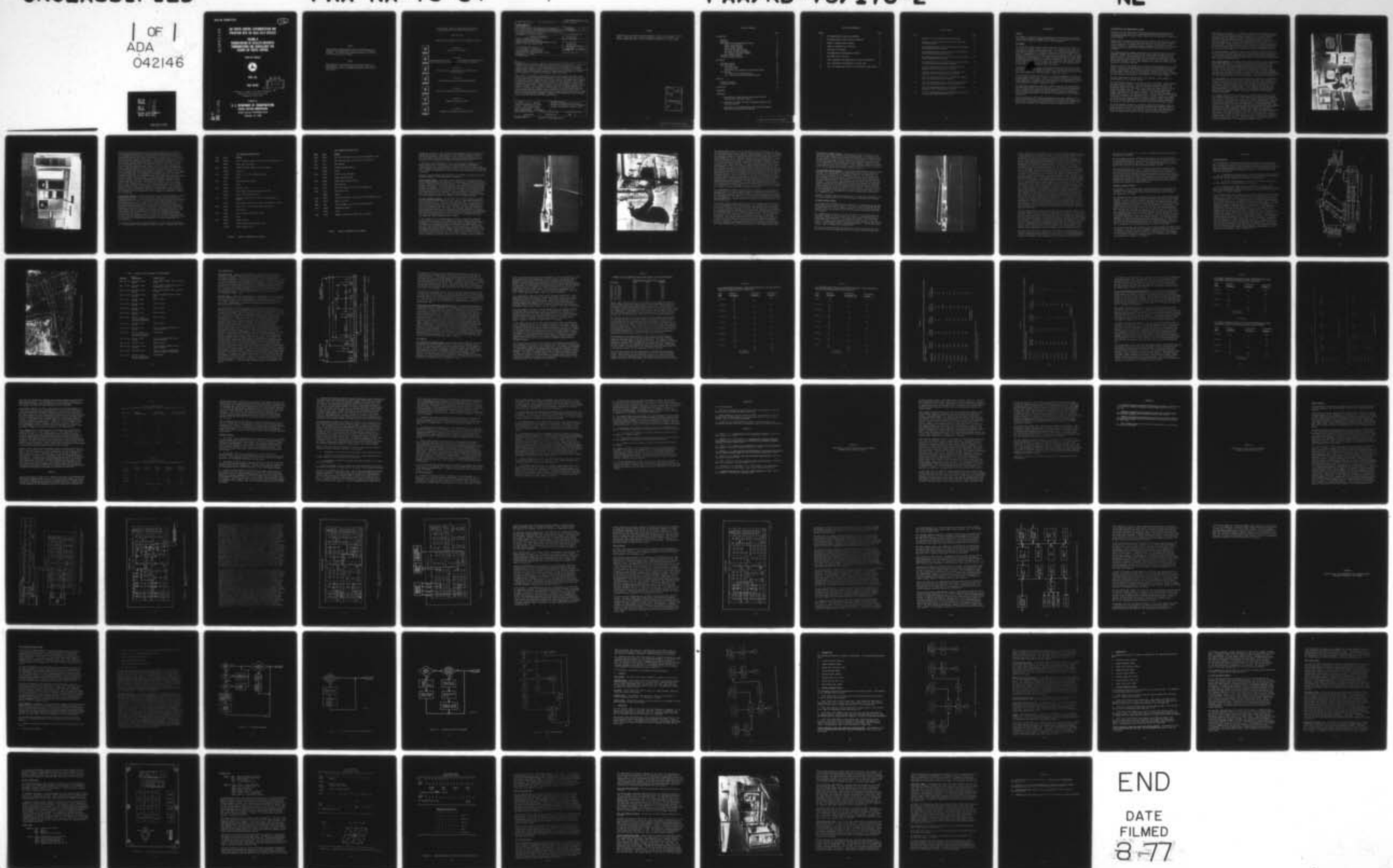

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Report No. FAA-RD-75-173-II

AIR TRAFFIC CONTROL EXPERIMENTATION AND EVALUATION WITH THE NASA ATS-6 SATELLITE

VOLUME II: DEMONSTRATION OF SATELLITE-SUPPORTED COMMUNICATIONS AND SURVEILLANCE FOR OCEANIC AIR TRAFFIC CONTROL

Francis W. Jefferson

APRIL 1976

FINAL REPORT

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NOTICE

NOTICE

AIR TRAFFIC CONTROL EXPERIMENTATION AND
EVALUATION WITH THE NASA ATS-6 SATELLITE

FINAL REPORT

THIS REPORT CONSISTS OF THE FOLLOWING VOLUMES:

VOLUME I

EXECUTIVE SUMMARY

VOLUME II

DEMONSTRATION OF SATELLITE-SUPPORTED COMMUNICATIONS
AND SURVEILLANCE FOR OCEANIC AIR TRAFFIC CONTROL

VOLUME III

SUMMARY OF U.S. AERONAUTICAL TECHNOLOGY
TEST PROGRAM

VOLUME IV

DATA REDUCTION AND ANALYSIS SOFTWARE

VOLUME V

MULTIPATH CHANNEL CHARACTERIZATION TEST

VOLUME VI

MODEM EVALUATION TEST

VOLUME VII

AIRCRAFT ANTENNA EVALUATION TEST

Technical Report Documentation Page

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16. Abstract

Demonstrations of satellite-supported communications for application to oceanic air traffic control (ATC) were conducted as part of an international ATS-6 L-band satellite test program. The ATC demonstrations were comprised of two phases: demonstrations conducted solely for United States (U.S.) Department of Transportation Federal Aviation Adminstration purposes and demonstrations conducted as a joint effort between U.S., European Space Agency (ESA), and Canada.

Voice, data, and dependent surveillance communications between air traffic controllers at a ground terminal and pseudopilots in two airborne aircraft, FAA KC135 and ESA COMET IV, were performed via the ATS-6 satellite and Rosman ground station. A simulated aircraft terminal located at Rosman was also employed. Each terminal provided up to six simulated data link aircraft, through computer software, for traffic loading purposes. Canada provided a voice-only simulated aircraft terminal located in Ottawa. Voice and data scenarios were used to create simulated air traffic. Results were: Dependent ATC surveillance was demonstrated through data link automatic aircraft position reports; position data were obtained from an inertial navigation system in the KC135 and an Omega navigation system in the COMET; and to a limited extent, independent surveillance was demonstrated using the NASA PLACE system and the ATS-6 and ATS-5 satellites.

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PREFACE

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INTRODUCTION

PURPOSE.

The purpose of this effort was to demonstrate and evaluate basic capabilities and conceptual methods of operations pertaining to the introduction of satellites in the oceanic air traffic control (ATC) environment.

BACKGROUND.

Air travel over oceanic areas involves operations where positive control is not currently possible because of the absence of coverage for both radar surveillance and reliable voice communication. Voice communication between aircraft and ATC facilities is primarily dependent on the high frequency (HF) band. HF communication is considered unreliable because the number of usable channels is limited at any one time, and propagation anomolies can cause fades or dropouts in communication. At present an acceptable level of flight safety is maintained by incorporating an airspace configuration that utilizes widely spaced flight tracks across the ocean, large separation times between aircraft as they enter the tracks, and periodic radio reports by the onboard aircrew as they pass certain checkpoints along the tracks.

A solution to the inadequacies of the present oceanic ATC service is a satellite relay system of continuous surveillance and communication coverage over the oceanic areas. The provision of such a satellite relay system provides the basis for establishing a positive control oceanic ATC system.

The next logical step in the evolution to a satellite-supported ATC system is an experimental program using a system of satellites dedicated to aeronautical experimentation and evaluation. This program, which is international in scope, is the Department of Transportation (DOT) Federal Aviation Admininistration (FAA) Aeronautical Satellite (AEROSAT) program.

The Applications Technology Satellite 6 (ATS-6) experiment ATC demonstration/evaluation was planned to provide information for the design and implementation of AEROSAT and to obtain preliminary experience in the utilization of a satellite-supported communication and surveillance system for oceanic ATC, the latter being applicable to the design of the AEROSAT test and evaluation program plan.

The ATS-6 experiment ATC demonstration/evaluation was both a dedicated U.S. DOT/FAA test program and a joint international test program; the latter with participation by the DOT/FAA Canadian Ministry of Transport and European Space Agency (ESA)--formerly the European Space Research Organization (ESRO).

DESCRIPTION OF ATC DEMONSTRATION SYSTEM.

In brief, the ATS-6 experiment ATC demonstration system featured satellite-supported real time data, voice, and ranging communications capability for use between specially equipped testbed aircraft and an experimental oceanic ATC ground terminal.

Controllers at the ground terminal were able to observe aircraft flight tracks updated every 2 minutes through data link automatic position reports relayed via the satellite. Provisions were also available for aircraft track and position updating by controllers manually inserting flight progress information received from voice communication transactions with the aircraft via the satellite.

Each testbed aircraft terminal provided data link position reports and flight operation messages that concerned the two real aircraft flightpaths and six imaginary aircraft flying simulated flight plans stored in a data link subsystem computer. Some novel features of the aircraft terminals were a pilot display and input/output device that would allow the pilot to display incoming and outgoing messages and send short messages, and a hard copy printer for the logging of all incoming messages.

Another provision of the demonstration system was the determination of the test aircraft's position independent of the automatic position-reporting data link system. This provision was implemented by means of an especially designed position determination system that used ranging communication relayed through two satellites. Aircraft position information provided by the ranging technique was also available for display to the controller at the ground terminal.

The ATS-6 experiment ATC demonstration system included a space segment, a ground segment, and an airborne segment.

The space segment consisted of the ATS-6 and ATS-5 satellites. Both satellites were geostationary satellites which functioned as radio relays between the ground and airborne segments. The ATS-6 satellite provided satellite communication channels for transferring voice, data, and ranging signals between ground and airborne terminals. The ground-satellite-ground communication channel frequencies were at C-band, 6350.000 to 6359.100 megahertz (MHz) transmit and 3950.552 to 3959.000 MHz receive. For aircraft-satellite-aircraft communication channels, the frequencies were at L-band, 1550.000 to 1559.100 MHz receive and 1650.552 to 1659.000 MHz transmit. The ATS-5 satellite provided the capability for relaying ranging (distance-measuring) signals only between ground and aircraft terminals for the aircraft position location experiment. The operating frequencies were 6212.750 MHz C-band and 1551.600 MHz L-band.

The ground segment consisted of a satellite communication-channel control terminal and "Position Location and Aircraft Communications Equipment" (PLACE) ground subsystem located at the National Aeronautics and Space Administration (NASA) facility at Rosman, North Carolina, and an oceanic ATC demonstration facility configuration located at the FAA National Aviation Facilities

Experimental Center (NAFEC). In addition to satellite and communication control functions, the Rosman facility was utilized to house a simulated aircraft terminal. A second simulated aircraft terminal with voice-only capability was provided by the Canadian Ministry of Transport at their Ottawa test facility. The NAFEC facility provided three positions for ATC operations, each with capability for voice and data communication transactions. The Rosman and NAFEC ground terminals were interconnected by three dedicated telephone circuits. A fourth telephone circuit, voice-only, interconnected Rosman and NAFEC via NASA telephone circuits routed through a communication center located at the NASA Goddard Space Flight Center (GSFC), Greenbelt, Maryland.

The airborne segment consisted of two specially equipped testbed aircraft, an FAA KC135, and an ESA-furnished Comet IV. Each aircraft provided experimental L-band avionics systems, operational-type satellite communication antennas, voice and digital communication and tone-ranging systems, and computer-operated data link and navigation systems.

NAFEC GROUND TERMINAL. The NAFEC ground terminal consisted of two minicomputers, Varian Data Machines 620/i and 620/f, each with associated teletypewriter input/output (I/O) devices, magnetic tape drives, and tape readers; three cathode-ray tube (CRT)-type information displays for display of aircraft position, tracks, and progress reports; and a seven-channel magnetic tape recorder for recording voice communication transactions. The 620/i computer controlled the information displays. Incoming and outgoing digital communication data were processed in the 620/f computer. One of the information displays, the Hazeltine model 2000, was used as the primary controllers I/O position.

All data messages sent from the ground terminal were entered at the Hazeltine 2000 keyboard or at the teletypewriter keyboard associated with the 620/f computer. Data messages sent from the airborne terminals were processed first in the 620/f computer and then in the 620/i computer for display on Information Display Inc. Input/Output Machine (IDIIOM) information displays. In addition to providing a keyboard entry to the computers, the two teletypewriters functioned as hard copy printers for incoming and outgoing digital communication exchanges. Figures 1 and 2 show the NAFEC ground terminal equipment complement.

The telephone circuits that interconnected the NAFEC ground terminal and the NASA Rosman facility consisted of three dedicated C-2-conditioned, alternate voice or data, full-duplex 3002 channels with customer switching provisions for configuration of each channel to either voice or data transmissions. The data circuits were interfaced to Bell Telephone System 205B2 switchable 600/1200/2400 bits-per-second (b/s) data sets installed at each ground terminal. Provisions for two other voice circuits were also made at the NAFEC ground terminal. These were full-duplex 2002 voice channels between NAFEC and the NASA GSFC communication center, Greenbelt, Maryland, and a direct-dial circuit or connection to Bell System commercial facilities through the NAFEC switchboard. The formerly described voice circuit was used for alternate access to the Rosman facility through the NASA Switching Conference and Monitor Arrangement (SCAMA) network, while the latter circuit was used to demonstrate the distribution and performance quality of satellite-supported voice communications to Aviation community users via conventional telephone circuits.

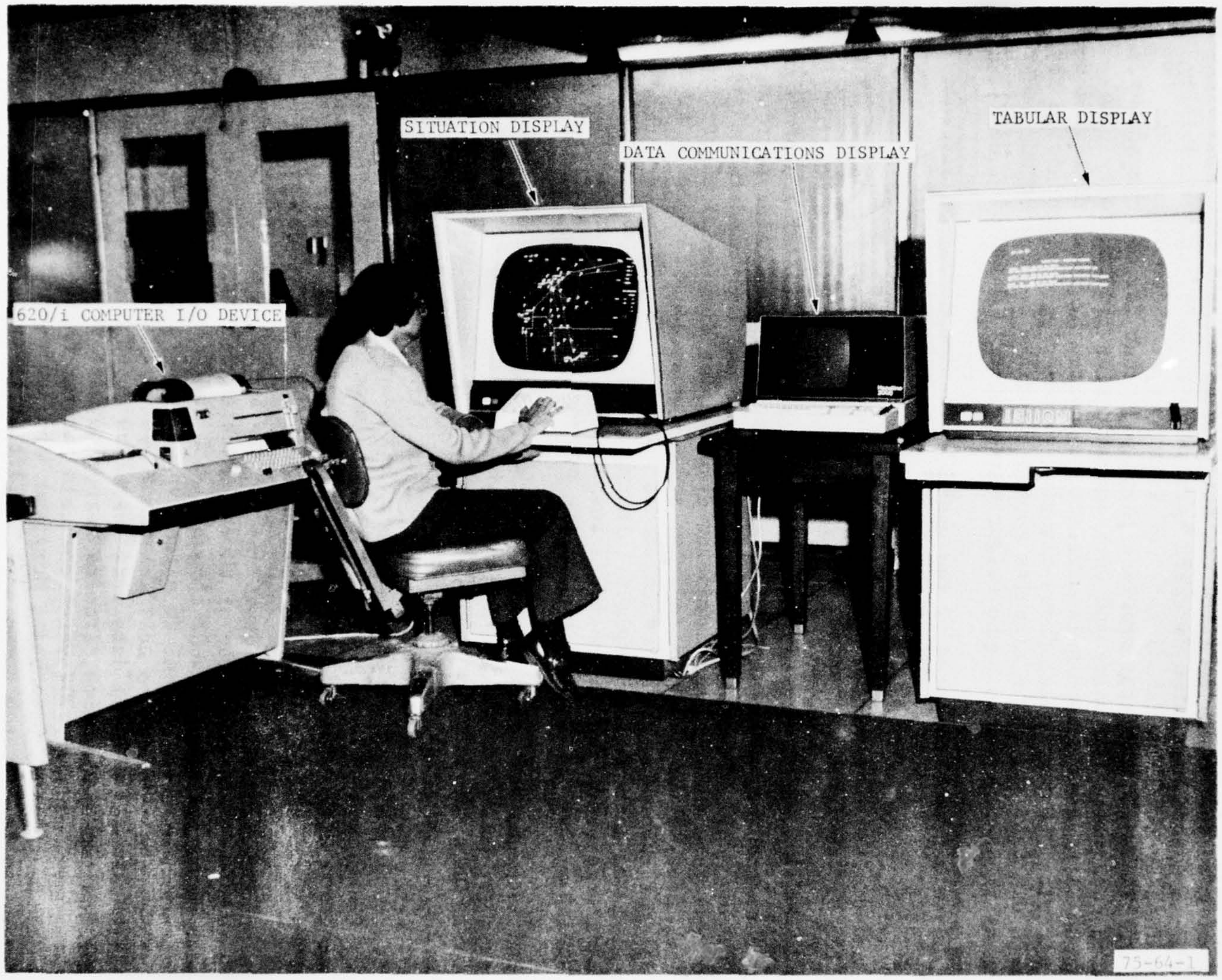


FIGURE 1. ATC DEMONSTRATION INFORMATION DISPLAYS

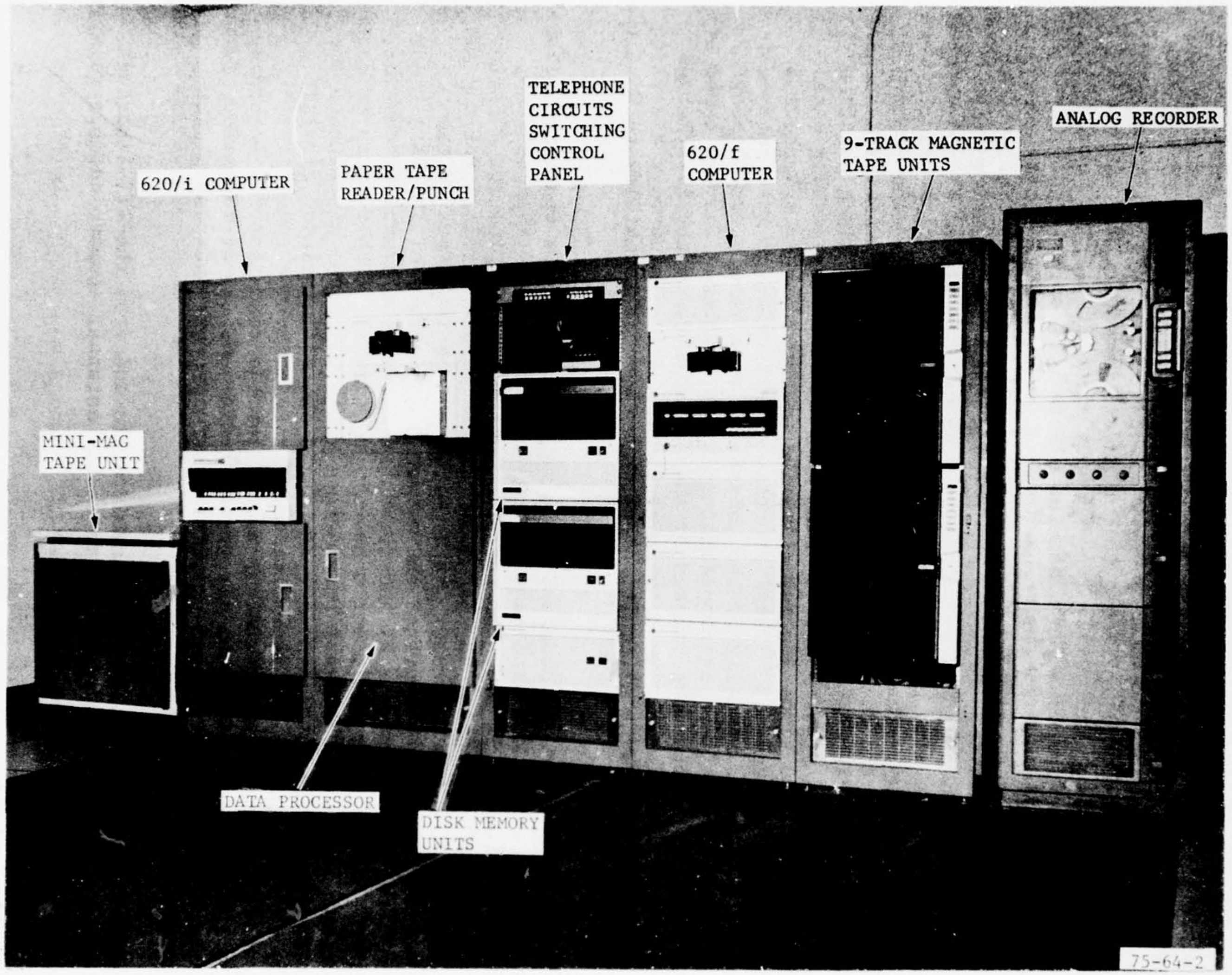


FIGURE 2. ATC DEMONSTRATION GROUND TERMINAL COMPUTERS

During the ATC demonstrations, the 620/f computer data processor polled the real and simulated aircraft for position reports and general text messages. It maintained the polling list of the aircraft entered at the beginning of a demonstration exercise and logged all messages on magnetic tape. Polling for automatic position reports was done every 2 minutes, while the polls for general text messages were executed every minute. Each airborne terminal had the capability of providing simulated voice and data aircraft traffic for loading the ATC demonstration system. The simulated aircraft of each aircraft data link terminal were assigned routes, speed, and altitude for each simulated flight. These variables could be changed by the air traffic controller during the demonstration exercise. Progress reports and other test messages were derived form prepared scenarios (a sample is presented in figure 3) and entered into the airborne data link computer by the pseudopilot. Position reports were provided automatically by the computer from software programs. The voice-simulated aircraft in the demonstration were also derived from prepared scenarios utilized at each aircraft terminal. The voice scenarios contained position reports, requests, and other aircraft-operations-related messages for each simulated aircraft, and times for reporting the messages. Figure 4 shows a sample of the voice scenarios. These progress report messages were entered into the 620/i computer manually by the controller upon receipt at the NAFEC ground terminal to update an extrapolation software program. The two types of aircraft, data, and voice were tracked by the controllers on the information displays by means of distinctive symbols, a rectangle for voice-only aircraft, and a diamond for data link aircraft. The system had the capability to handle up to 20 aircraft.

ROSMAN GROUND TERMINAL. The Rosman Station was NASA's primary spacecraft control communication interface and data acquisition facility for the applications technology satellites. It was also the principal ground station for experimenter operations with ATS-5 and 6. The function of this ground terminal for the ATC demonstration system was fourfold: (1) It provided the interface to the ATS-6 spacecraft through the ground and aircraft equipments of the NASA PLACE subsystems (reference appendix A) and furnished all of the signal processing, transmitter, and receiver equipment necessary to transfer either voice or data communication from the Government Data Access (GDA) telephone circuits to the user terminals via the satellite; (2) it housed the FAA-simulated aircraft terminal; (3) it provided the means for monitoring satellite communication channel status and performance quality as well as the resources for recording the voice and data communications for postanalysis; and (4) it furnished, through its resources, the collection and computation of aircraft independent surveillance data.

Voice and data communications were transmitted to and from the ATS-6 through an 85-foot-diameter C-band parabolic reflector antenna. Communications relayed

C135 SIMULATED AIRCRAFT DATA

TIME	ACID	MESSAGE
0005	A56281	Low oil pressure Engine #3, may return to Atlantic City.
	NAFEC	Roger, keep me advised.
0009	NAFEC	(A56281) Request number of souls on board.
	A56281	Roger, 52.
0013	A56281	Engine #3 O.K., proceeding on course.
	NAFEC	Roger.
0017	AA14	Climbing through 15,000.
	NAFEC	Roger.
0021	EA1401	Request FL 190.
	NAFEC	Roger EA1401, descend and maintain FL 190.
	EA1401	Roger EA1401 leaving FL 200.
0025	AF101	Request to deviate 50 mi. west of course because of weather.
	NAFEC	Roger AF101, deviation approved, report back on course.
0029	NAFEC	AF101 Are you still heading away from course?
	AF101	Affirmative.
0033	AF101	We are turning back toward course.
	NAFEC	Roger.
0037	EA1401	Request FL 160.
	NAFEC	EA1401 Descend and maintain FL 160.
	EA1401	Roger Leaving FL 190.

FIGURE 3. SAMPLE OF PREPARED DATA SCENARIO

C135 SIMULATED AIRCRAFT VOICE

TIME	ACID	MESSAGE
0008	AA395	(PR) by 3823/02710 @ 05, FL 40, ETA 4000/04000 @ 1+34.
0012	UA14	(PR) over Sea Isle @ 06, 5000 ft., ETA Shad @ 29.
0016	C135	Crew Message.
0020	VVL70	Climbing through 8000 ft.
	NAFEC	Roger.
0024	NAFEC	AA395 Say your altitude.
	AA395	Roger, leaving FL 200.
0028	NAFEC	VVL70 Report leaving FL 180.
	VVL70	Roger will do.
0032	UA14	(PR) over Shad at 29, FL 260, ETA Berman 42.
0036	UA14	Level at FL 280.
	NAFEC	Roger.
0040	VVL70	(PR) by 3512/05600 @ 36, FL 190, ETA 3440/06000 @ 1+12.
0044	VVL70	Level @ FL 200.
0048	UA14	(PR) by Berman @ 42, FL 280, ETA Cullen 1+20.
0052	VVL70	Operations normal.
	NAFEC	Roger.
0056	AA395	Request to deviate 50 miles east of course.

FIGURE 4. SAMPLE OF PREPARED VOICE SCENARIO

through the satellite to and from the Rosman simulated airborne terminal were transmitted through a 15-foot-diameter L-band parabolic reflector antenna. Backup for the primary C-band antenna and for C-band transmissions to the ATS-5 in support of the two-satellite position-determination experiment was provided by a 15-foot-diameter parabolic reflector antenna also.

In addition to the aforementioned, the ATC demonstration equipment at the Rosman ground terminal consisted of the normal complement of telephone company patching and circuit-equalizer equipments and 205B2 data sets, especially designed voice and data interface units which provided signal conversions, voice squelch, and amplification for the PLACE system and magnetic tape recorder interfaces.

Appendix B contains additional information on the NAFEC and Rosman ground terminals and details of the operation and interfaces.

OTTAWA GROUND TERMINAL. The Ottawa Canada ground station configuration for the ATC demonstration system consisted of a transmitter, reciever, and 19-foot-diameter L-band parabolic reflector antenna. This equipment configuration which provided capability for voice communication only was provided by the Canadian Ministry of Transport. The Ottawa terminal functioned as a simulated aircraft terminal participating in voice communication exchanges with the NAFEC ground terminal through the NASA Rosman PLACE C-band channels and the dedicated telephone lines between Rosman and NAFEC. Prepared scenarios of simulated aircraft operations were used by the Canadian communicators to provide additional voice-only aircraft air traffic loadings for the ATC demonstrations.

FAA KC135 AIRBORNE TERMINAL. The FAA KC135 jet aircraft (figure 5) provided the FAA aircraft testbed terminal for both the U.S. dedicated ATC demonstrations and the joint U.S., ESA, and Canada demonstrations. The KC135 test aircraft terminal consisted of the data link subsystem, PLACE transponder, an inertial navigation system,(INS) L-band antennas, selective calling (SELCAL) unit, and a universal time (UT) clock. The data link subsystem contained a digital message processor, pilot keyboard and display, pseudopilot keyboard and display, hard copy printer, and the required interfaces for those equipments which provided aircraft altitude, heading, position in latitude and longitude, and the UT clock and PLACE transponder. The PLACE transponder contained a data modem and L-band transmitter and receiver.

In the operation of the ATC demonstration system, the data link subsystem accepted digital signals from the PLACE data channel, decoded the message according to a fixed format, executed a block check and parity check, matched the address in the incoming message, and displayed the information on the particular output device designated by the incoming message. The data link subsystem also accepted digital signals from the various input devices of the ATC demonstration system on the aircraft, arranged the information in the proper format, converted the data to a data stream, and presented it to the PLACE transponder for transmission to the ground terminal. The pseudopilot's position (principal operator's position for the ATC demonstrations, figure 6)

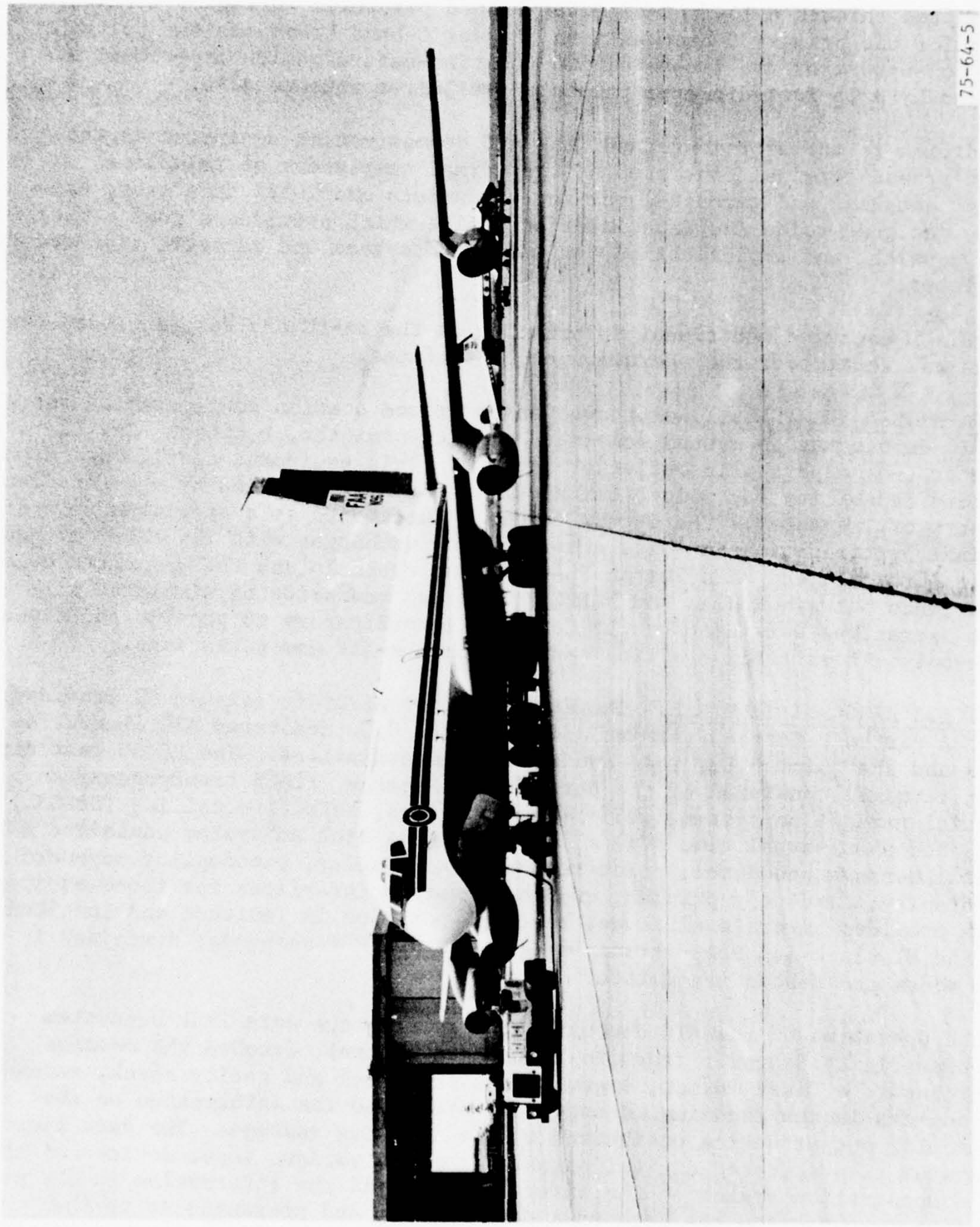


FIGURE 5. FAA KC135 JET AIRCRAFT

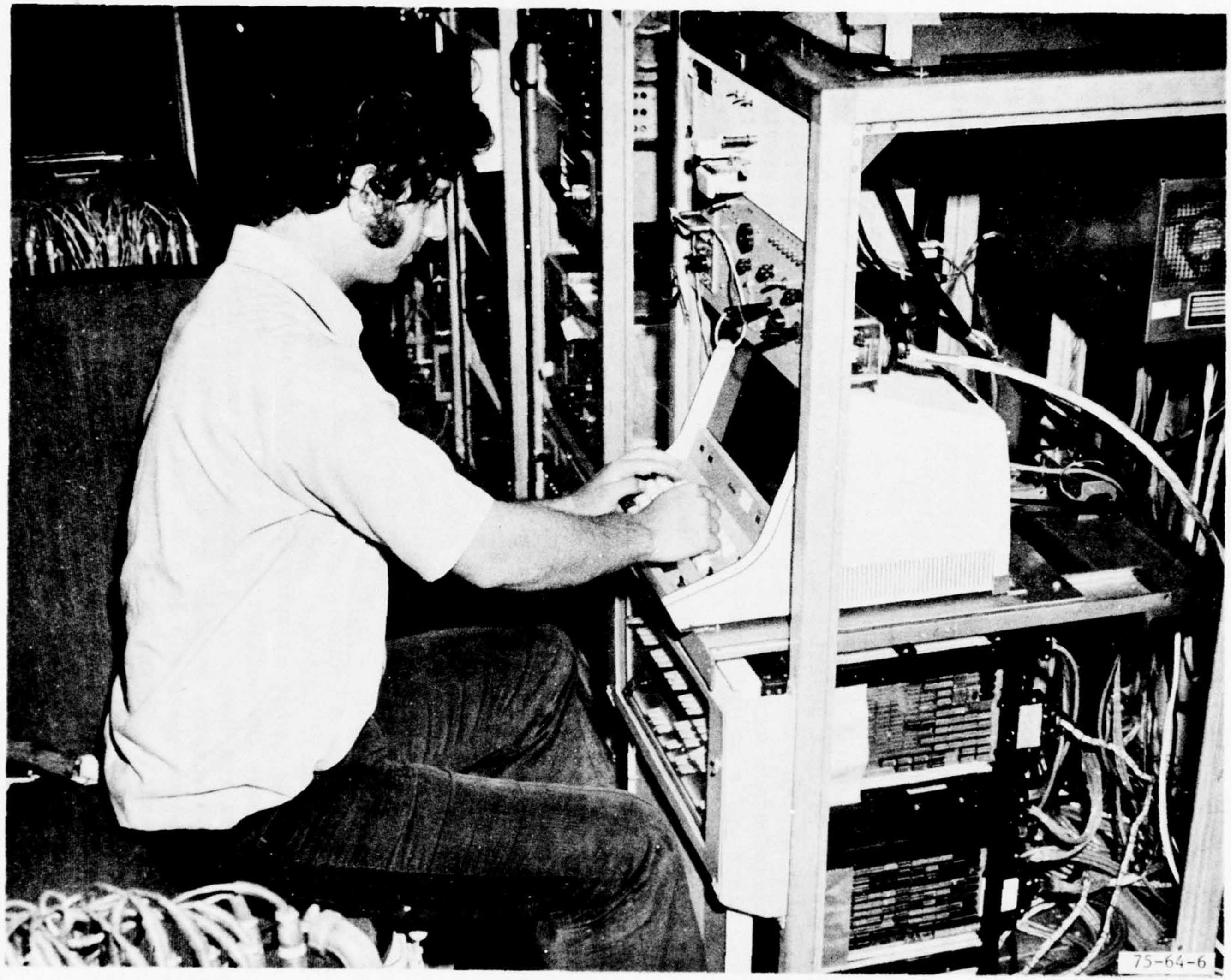


FIGURE 6. FAA DEMONSTRATION PSEUDOPILOT POSITION

was used for both the real time flight vehicle and for simulating other aircraft simultaneously with the real time flight operation. In order to increase the data link aircraft traffic loading, software programs were used in the data link subsystem computer to generate simulated position reports and flight progress messages for up to 6 simulated aircraft and 14 prestored routes. A new route, a deviation from a route, or a change in airspeed, windspeed, wind direction, or flight level could be made by entries into the keyboard display for any aircraft being simulated. The data link subsystem computer had the capability for accepting two kinds of polling; general polling, which enabled the pseudopilot to send to the ground terminal clear-text messages for the simulated aircraft and the real (host) aircraft, and aircraft position polling, which enables the ground to automatically receive altitude and INS latitude and longitude position data from the real aircraft and calculated position for the simulated aircraft as well as windspeed and wind direction for the real and simulated aircraft. The INS data input to the data link subsystem were the following: present position, groundspeed, track angle, true heading, windspeed and wind angle. Present position was also available for display on a slave indicator unit at the pseudopilot position for use in the two satellite position-determination experiment. The data link subsystem also provided a real time clock and a memory capability for storing 8 to 15 messages in a total of 700 characters. All messages in and out of the airborne data link terminal were logged by a paper tape punch and hard copy printer.

Voice communication operation at the pseudopilot position was implemented by interconnections to a special NAFEC-designed and fabricated audio patch and switching unit. This unit provided access to the PLACE voice channel for both the pilot and pseudopilot and access to the aircraft intercommunication system for the pseudopilot. In addition, this unit contained the PLACE-remoted status lamp indicators and associated circuitry as well as the FAA SELCAL visual and audible indicators.

The aircraft L-band antenna system used for the ATC demonstrations consisted of three flush-mounted slot dipole antennas. One of each antenna was mounted in the left and right upper wing/body (wing root) fairing areas at aircraft station 766. These two antennas provided ±4 decibels (dB) gain (with respect to a right-hand circular isotrope) side coverage from approximately 10° to 165° in the azimuth plane (point of reference being the nose of the aircraft) and from 10° to 75° above the horizon in the vertical plane. The third antenna was mounted on the top fuselage, approximately centerline, at aircraft station 805. This antenna provided ±4 dB gain (with respect to a right-hand circular isotrope) overhead and fore and aft coverage from 10° above the horizon to the zenith. Since the flightpaths were all made at aircraft-to-satellite elevation angles between 40° and 10°, the right and left wing root slot dipole antennas were used the major portion of each demonstration period.

ESA COMET IV AIRBORNE TERMINAL. The Comet IV jet aircraft (figure 7) was used by ESA in support of the joint ATC demonstrations. The data link subsystem and audio communications patching and switching unit furnished by the FAA were similar to that installed in the FAA KC135 aircraft. The data link subsystem was interfaced to ESA L-band avionics equipment (receiver, transmitter, and modem) which performed similar and compatible functions to that of the PLACE used in the FAA aircraft. Other equipment provided by ESA were L-band antennas and an Omega navigation system that was utilized as the data source for the automatic-positioning reporting function.

FAA SIMULATED AIRCRAFT TERMINAL. The FAA ATC demonstration simulated aircraft terminal, which was located at the NASA Rosman, North Carolina, facility, consisted of a configuration of equipment similar to that employed in the KC135 airborne terminal for the pseudopilot position. In the operation of this terminal's data link subsystem to support the ATC demonstration, only the six simulated aircraft were utilized. The voice-only simulated aircraft operations were the same as those employed for the other three aircraft-type terminals. Voice and data communication transactions between the simulated aircraft terminal and the NAFEC ground terminal were supported by the PLACE L-band channels to and from the satellite and the PLACE C-band channels and dedicated telephone circuits to NAFEC from the satellite to ground. Location of the simulated aircraft terminal at the Rosman facility was necessitated by the requirement to interface with the only available PLACE system which was furnished by NASA.

Appendix B contains additional information on the three ATC demonstration aircraft-type terminals and details of the operation, interfaces, and software.

SOFTWARE--GROUND TERMINAL.

The software in the ground system was composed of two subsystems; the communication and control subsystem, which was resident in the 620f minicomputer and occupied about 16k of the 32k memory, and the air traffic control and display subsystem, which was resident in the 620i minicomputer and utilized the full 32k of memory.

The communication and control subsystem was composed of an initializing routine which readied all the I/O devices and cleared the appropriate buffer in preparation for the execution of the operational program. The operational program had a main loop with the following eight main processors: real time clock, I/O character under interrupt control, console monitor, aircraft polling control, receive message monitor, logging message monitor, IDIIOM transmission monitor, and the ranging data receive monitor.

The real time clock kept track and updated the system time at specified intervals, such as every 10 milliseconds (ms) so that other processors knew when

FIGURE 7. ESA COMET IV JET AIRCRAFT

certain tasks were to be performed. The I/O-character-under-interrupt-control routine inputted and outputted characters from the peripheral devices only when a character was ready, so as not to tie up the computer waiting for it to become ready, since the computer was at least 100 times faster than the I/O devices. The console monitor processed the different types of messages that an air traffic controller sent to an aircraft. It also displayed all the messages from an aircraft on the appropriate consoles so that an air traffic controller could take the appropriate action. As required, it was also responsible for all the control messages that set up the system parameters, such as the number of aircraft in the system, the waiting time for a response from an individual aircraft, the polling-cycle time, and the ON or OFF status of devices in the system. The aircraft polling control determined which aircraft had to be polled, the type of message they should be polled for, and when they should be polled again. The receive-message monitor decoded all the incoming messages, put the appropriate device address on them, and then stored them in the main buffer. The logging-message monitor checked the main buffer to see if any messages had not been logged on the nine-track magnetic tape and if not, logged the message, either forward link or return link. The IDIIOM transmission monitor set up the required linkage on its side, then sent position reports on each aircraft through the interface to the other computer system to be displayed on the controller's information displays. The ranging-data receive monitor inputted position data from a PDP-11 minicomputer at Rosman, North Carolina. The PDP-11 minicomputer at Rosman computed the position (latitude and longitude) of the aircraft by computing the time difference between two ranging signals, one from the ATS-6 and the other from the ATS-5. The position information was transmitted from the PDP-11 in the same format as a data link message from a test aircraft. It was sent over one of the dedicated telephone lines through a modem to the 620f computer. The 620f transmitted it through the E1400 interface to the information display system. The normal data link position information came from an onboard INS, and the PDP-11 position came from the PLACE system independent surveillance capability. This arrangement enabled simultaneous demonstration of two aircraft position reporting techniques.

The ATC subsystem was comprised of four main processors, the ATC function subprograms, graphic display subprograms, input message processor, and a data link processor. The ATC function subprograms did all the calculations on the flight data to update positions on the information displays at certain time intervals. They were devised to predict future conflicts between aircraft, in order to alert the air traffic controller of the upcoming situation. The programs also warned the controller of aircraft that had not reported over their last fix. The subsystem also handled the wind information transmitted to it from the aircraft and set up wind tables for any aircraft flying in the oceanic system. The graphic display subprograms took the information that was updated by the ATC programs and displayed it in specified formats on the information displays.

There were two main display formats, the situation and tabular displays. The situation display let the controller see an aircraft in a latitude/longitude grid map with standard fixes over the Atlantic Ocean. The tabular display contained all the numeric data associated with each aircraft such as last fix,

next fix, speed, altitude, etc., so that a controller could see the detailed information if required.

The input message processor controlled, initialized, and set up the entire ATC and display subsystem. It also handled flight plans on aircraft that would be entering the system and inputs to the computer manual updates for voice-only aircraft that were in the system. The computer programs were devised to handle both voice-only and voice- and data-equipped aircraft.

The data link processor was used to control position report messages from data-link-equipped aircraft only. It executed commands for the connection of data circuits between the communication subsystem and the ATC subsystem. When the circuit was completed, the computer transmitted the digital communication message through the E1499 hardware interface to the data link processor. The processor checked the message for syntactical correctness and provided the required data conversions. For example, position report messages contained latitude and longitude data that needed to be converted into system units for display on the situation information display.

SOFTWARE--AIRBORNE TERMINAL.

The software for the airborne system consisted of two major subsystems; the communication and control subsystem, which utilized 6k of the 8k memory in the 620/L - 100 minicomputer, and the simulator subsystem, which required the remaining 2k of memory.

The communication and control subsystem included the data link processor, pilot keyboard and display processor, pseudopilot keyboard and display (Asciscope®) processor, hard copy printer processor, and paper tape punch processor. Functionally, the data link processor was responsible for receiving forward-link (ground-to-aircraft) messages, unpacking the messages, and routing them to the addressed onboard output device. It was also responsible for obtaining information from the onboard input devices viz, the INS, pilot keyboard/display and Asciscope, and formatting the data for transmission to the ground terminal. The Asciscope processor was responsible for the display of forward-link text messages and for executing keyboard commands from the pseudopilot. The pilot keyboard/display processor was responsible for the accepting and display of messages addressed to that device and the execution of the pilot keyboard commands of return-link (aircraft-to-ground) messages. The hard copy printer and paper tape punch processors had similar responsibilities of service loging all data link message transactions at the airborne terminal. Flow diagrams for the above-referenced processors and a more detailed description of the programming of each peripheral device is provided in appendix C.

The simulator subsystem was comprised of the programs required to simulate the flightpaths of six aircraft with accompanying position reports and text messages. The simulator included a number of operator (pseudopilot) initiated control functions which were entered through the Asciscope keyboard. Flow diagrams of the simulator subsystem and further details of the programs that comprise the simulator are contained in appendix C.

DISCUSSION

EXPERIMENT DESIGN.

The ATC demonstration tests were designed to demonstrate the use and management of voice-only, combined voice and data, data-only, and combined voice, data, and ranging systems for direct controller-to-pilot communication exchange, manual and automatic aircraft position reports, and aircraft position determination through independent surveillance functions. The objectives of the tests were as follows:

a. To demonstrate the capability to transmit and receive typical oceanic ATC messages through utilization of satellite-relayed voice, data, and ranging channels for selected airborne and ground user configurations;

b. To evaluate and demonstrate the quality of satellite-relayed voice and data channels in a quasi-operational environment;

c. To excerise the voice, data, and surveillance modes in a quasi-operational environment to acquire preliminary data for determining how a voice, data, and ranging system could best be utilized to provide services required for oceanic ATC message functions.

The ATC demonstrations were divided into two phases; tests that were conducted solely for U.S. purposes and tests conducted as a cooperative U.S., ESA, and Canadian joint effort. Figure 8 shows the system configuration used for the ATC demonstrations. The U.S. dedicated demonstration flights were conducted over the North Atlantic ocean primarily between the terminal points of NAFEC, Atlantic City, New Jersey, and Lajes Air Force Base in the Azores. The flightpaths were generally along the 40° North Latitude line and transversed satellite-to-aircraft elevation angles from 40° to 10°. Joint demonstration flights were conducted as round-robin flights out of the NAFEC and Lajes terminals and the Loring Air Force Base, Limestone, Maine. Each of the demonstration flights involved 4 hours of demonstration time. Figure 9 shows a map of the flight area on which is superimposed the 3-, 6-, and 10-dB antenna gain contours of the ATS-6 L-band fan-beam antenna. The spacecraft's fan-beam antenna was used for all of the ATC demonstrations, and its pierce point was normally 40° North Latitude and 45° West Longitude. A summary of the ATC demonstration flights is presented in table 1. It should be noted here that during the interim periods between ATC demonstrations when the FAA KC135 testbed aircraft was in the Azores and at Loring, it was used to support the technology phase of the ATS-6 experiment. This effort was conducted by the DOT Transportation Systems Center, Cambridge, Massachusetts, and is reported on in separate volumes of this report.

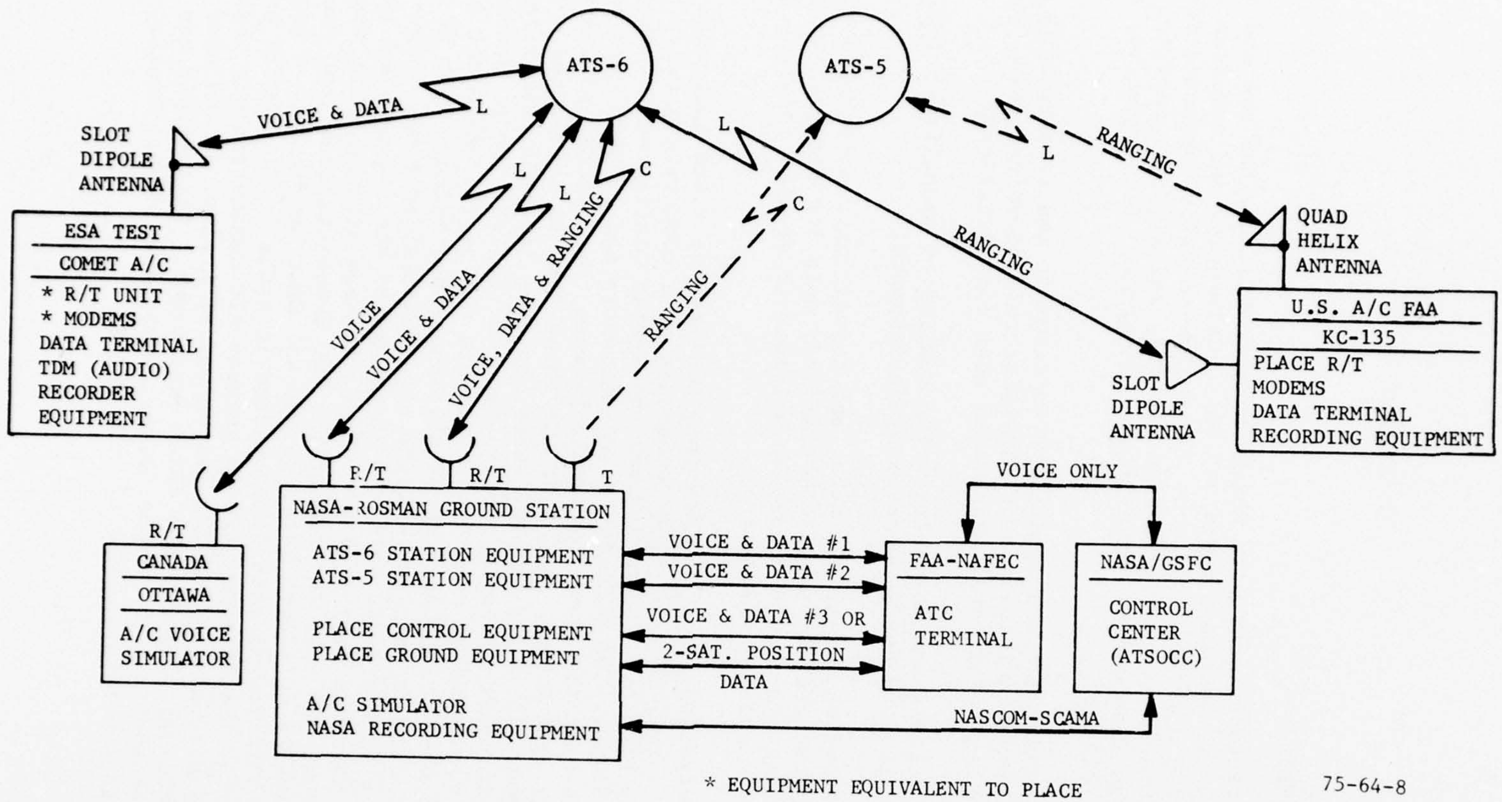
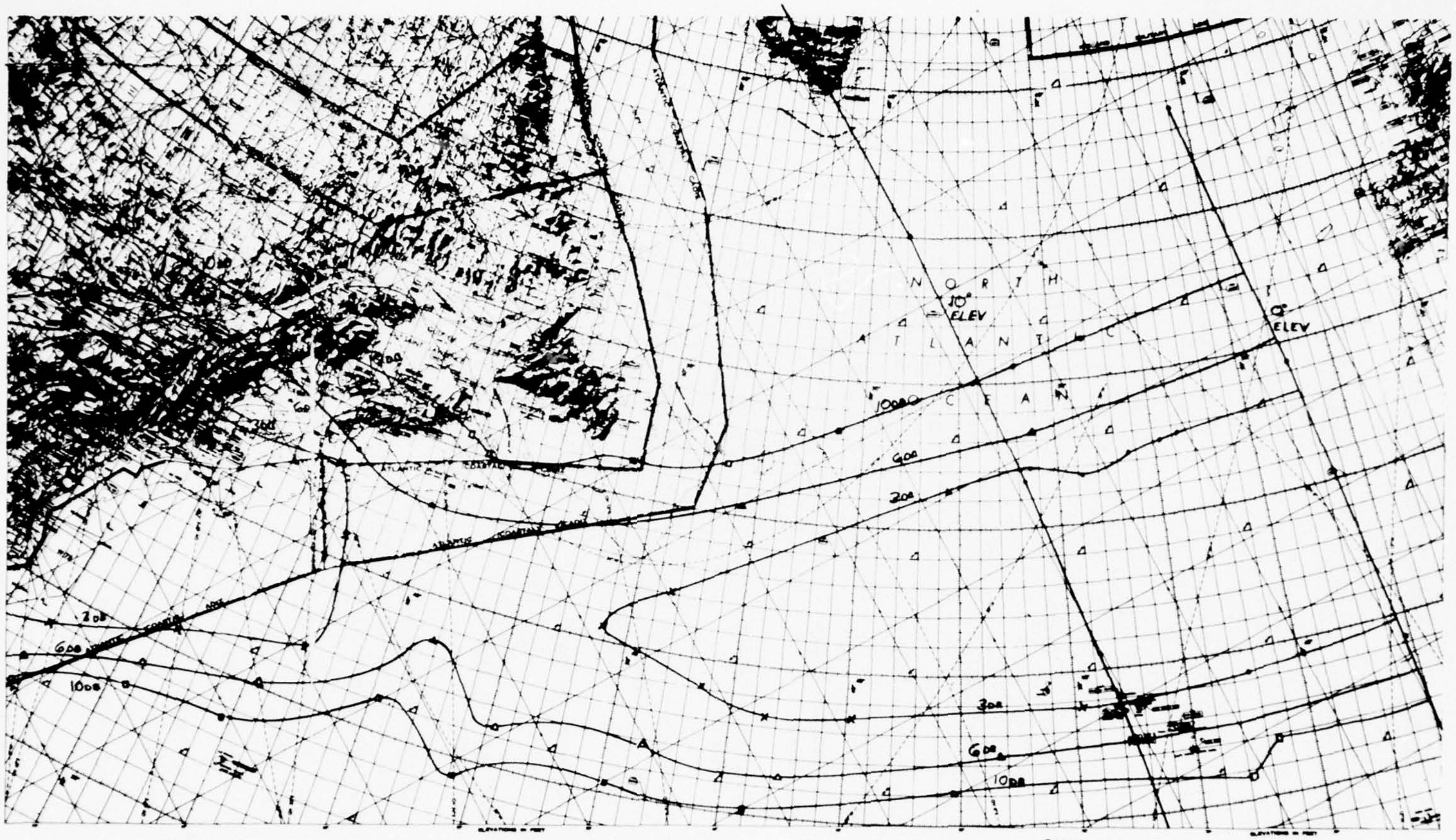


FIGURE 8. ATS-6 EXPERIMENT ATC DEMONSTRATION SYSTEM CONFIGURATION



2LAT = 18.75°N
2LONG = 58.5°W
PIERCE POINT = 40°N 45°W

75-64-9

FIGURE 9. ATS-6 EXPERIMENT ATC DEMONSTRATION FLIGHT AREA

TABLE 1. SUMMARY OF ATS-6 EXPERIMENT ATC DEMONSTRATIONS

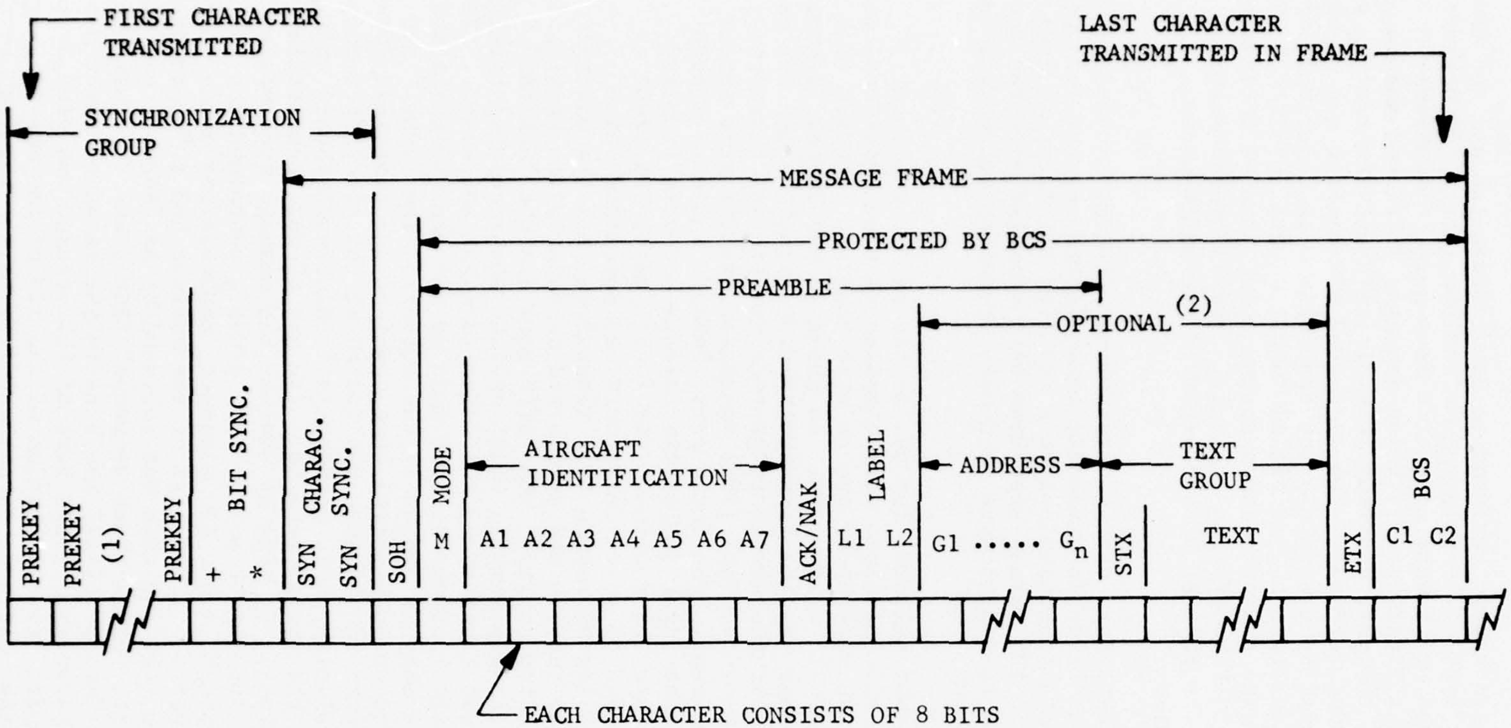
Test Date	Type Of Demonstration	Terminal Points
Sept. 20, 1974	Joint Demo - Voice and Data	KC135 - NAFEC to NAFEC; Comet - on Ground at NAFEC
Sept. 23, 1974	Joint Demo - Voice and Data	KC135 - NAFEC to Loring; Comet - NAFEC to Greenwood, Nova Scotia
Sept. 25, 1974	Joint Demo - Voice and Data	KC135 - Loring/Loring; Comet - on Ground at NAFEC
Sept. 27, 1974	Joint Demo - Voice and Data	KC135 - Loring/Loring; Comet - NAFEC to NAFEC
Oct. 1, 1974	FAA Demo - Voice and Data	Loring to NAFEC
Oct. 23, 1974	FAA Demo - Voice and Data	NAFEC to Azores
Oct. 29, 1974	FAA Demo - Voice and Data	Azores to NAFEC
Nov. 12, 1974	FAA Demo - Voice and Data	NAFEC to Azores
Nov. 22, 1974	FAA Demo - Voice Data, and two-Satellite Position Determination	Azores to NAFEC
Jan. 22, 1975	FAA Demo - Voice and Data	NAFEC to Azores
Jan. 31, 1975	FAA Demo - Voice and Data	KC135 - on Ground in Azores due to Weather Conditions
Feb. 1, 1975	FAA Demo - Voice Data, and two-Satellite Position Determination	Azores/NAFEC
Mar. 20, 1975	FAA Demo - Voice and Data	KC135 - on Ground at NAFEC due to weather conditions
Mar. 21, 1975	FAA Demo - Data	NAFEC to Azores
Mar. 24, 1975	Joint Demo - Voice and Data	KC135 - Azores to Azores; Comet - on Ground in Azores
Mar. 26, 1975	Joint Demo - Data	KC135 - on Ground in Azores due to high winds; Comet - Azores/Azores
Apr. 3, 1975	FAA Demo - Voice Data and two-Satellite Position Determination	Azores/Loring

TESTS DESCRIPTION.

VOICE-ONLY TESTS. These tests were designed to demonstrate the use and management of a satellite-relayed voice-only communications system for oceanic ATC message functions. The tests were conducted in a quasi-operational environment consisting of typical two-way voice messages initiated and responded to by the pseudopilots of the participating test aircraft and air traffic controllers at the NAFEC ground terminal. The simulated air traffic was generated from prepared scenarios used by the pilots and controllers as described previously in this report under the section titled "NAFEC GROUND TERMINAL." The tests used one- and two-voice channels and a shared voice channel to investigate and demonstrate candidate operating concepts, channel access methods, and queuing techniques. The FAA SELCAL was employed for voice-channel (tone-ringing) response alert.

DATA-ONLY TESTS. These tests were designed to demonstrate the use and management of a satellite-relayed 1200-b/s data-only communication system for oceanic ATC message functions. Data transmissions in a modified Aeronautical Radio Inc. (ARINC) characteristic 586 format were used with selected airborne and ground user configurations to demonstrate candidate operating concepts in a quasi-operational environment.

The modified ARINC 586 format selected for use in the ATS-6 experiment is shown in figure 10. Data link messages were composed of nine functional parts. Each part of the message was made up of one or more American Standard Code for Information Interchange (ASCII) characters. As shown in the format (figure 10), the first part of the message was the "synchronization group", which was used to lock-up the data modems in the system to provide for bit and character synchronization. A "start-of-heading" (SOH) character was the next part, indicating the start of message. The third part, "mode", included a mode character, which defined what input device the message had come from and whether the message was urgent or routine. The fourth part, "aircraft identification", was composed of seven characters and specified which aircraft the message was being addressed to. (Therefore, all the aircraft in the data link system had to receive and decode the message before knowing if the message was being directed to it.) The fifth part was the "ACK/NAK" character, or technical acknowledgement, which advised the receiving terminal whether its last message was received by the other terminal addressed. (If it was not, a repeat of the previous message was made on the next transmission instead of sending the new message stored in the buffer.) The "label" and "ground address" (sixth and seventh parts) were combined and contained four characters that defined where the message was routed at the aircraft terminal (to the printer, pilot's display unit, pseudopilot's display/keyboard unit, or logging device), or at the ground terminal, (to any of three controller positions and display devices), as well as whether the message type was general text or position report. The eighth part, "text group", contained the control characters for the text itself; i.e., ATC messages, requests for voice channels, and automatic position reports. (This part of the message had a "start-of-text" character (STX) before the text and then was followed by an "end-of-text" (ETX) character.) The final part, "block check sequence" (BCS), was two characters and contained a numerical "oring" of all the bits in the message from the SOH character on to the ETX character. (This part of the message was used by the receiving computer to compare its calculation of the BCS of the message with the BCS transmitted. If they matched, an acknowledgement was returned to the sender.)



(1) NUMBER OF PREKEY CHARACTERS IS SUFFICIENT TO LOCK UP ALL THE DATA MODEMS IN TRANSMISSION NETWORK.

(2) MAXIMUM COMBINED LENGTH OF OPTIONAL FIELDS INCLUDING "STX" IS 221 CHARACTERS.

75-64-10

FIGURE 10. ATS-6 ATC DEMONSTRATION DATA LINK TRANSMISSION FRAME FORMAT

Data messages consisted of typical communications exchanges as initated and responded to by the pseudopilots of the participating test aircraft and air traffic controllers. The simulated air traffic was generated from prepared scenarios used by the pilots and controllers as described in this report under the section titled "NAFEC GROUND TERMINAL". Dependent surveillance of multiple users was demonstrated. The testbed (real) aircraft position which was derived from an ARINC characteristic 561 INS, and altitude data were automatically transmitted through the data link in response to coded polling. The simulated test aircraft also provided simulated position and altitude data as generated by the data link subsystem.

A maximum of six simulated aircraft per test aircraft terminal were available for use in the demonstrations. The real and simulated aircraft position data were displayed on the controllers' tabular and situation displays. The polling technique used for all of the demonstrations except two was to repeat the poll of a test aircraft once before proceeding to the next aircraft. Multiple polls of each test aircraft and single-polls-only techniques were used for one demonstration each.

VOICE, DATA, AND INDEPENDENT SURVEILLANCE TESTS. These test were designed to demonstrate the use and management of a combined voice/data/ranging satellite-relayed communication system for oceanic ATC functions in a quasi-operational environment. A single PLACE voice channel with FAA SELCAL tone ringing, a time-multiplexed 1200-b/s data channel, and a two-satellite (ATS-6 and ATS-5) ranging technique using PLACE range tones and the surveillance and ranging (S/R) channel provided the test communications and independent surveillance demonstration media. Message exchanges between test aircraft pseudopilots and the controllers for both voice and data functions were similar to that described in the preceding sections concerning the voice-only and data-only tests. Testbed aircraft positions as obtained from both dependent and independent surveillance systems were displayed on the controllers situation display. The ESA Comet IV aircraft was not able to participate in the two-satellite position-determination tests with the FAA KC135 aircraft, due to the lack of proper equipment. In lieu of this, it interrupted link participation for 10-minute periods in each flight hour of the ranging tests to acquire ranging data via the S/R channel, with line-of-position data provided by the Rosman PLACE PDP-11 computer. Each testbed aircraft was assigned a specific time slot in the PLACE S/R-channel polling sequence.

TEST RESULTS.

U.S. DEDICATED ATC DEMONSTRATIONS. Voice communication between the KC135 testbed aircraft and the ATC ground terminal at NAFEC were, in general, of good quality for the major portion of the test period during all of the demonstrations. On those occasions when voice communication quality was degraded, it was normally due to either a breakdown or fault in those parts of the communication system external to the ground-air-ground satellite link. Since the objective of this aspect of the ATS-6 experiment was to demonstrate the quality of ATC voice communications supported by satellite relay, the reduced performance, caused by factors not inclusive to the satellite system, were discounted in the assessment of the performance quality.

During ATC demonstrations conducted from October 29, 1974, through April 3, 1975, voice communication exchanges between the KC135 aircraft and various DOT/FAA management and technical offices and aviation community offices were made through the special NAFEC ground-terminal FTS and direct-dial telephone provisions. The voice communication performance during these demonstration periods was considered of good quality by all those who participated. One such message transaction was with an oceanic air traffic controller at the New York Air Route Traffic Control Center (ARTCC). His enthusiastic evaluation of the voice communication quality was: "That was the best communication I have had in my 4 years experience working oceanic air traffic control".

Voice communication reception at the aircraft terminal was affected by background noise levels from aircraft engines, alternating current (a.c.) power converters, and various equipment motors. These noise levels tended to mask the intelligibility of the communications received and necessitated use of standard earmuff-type headsets in lieu of the now popular Telex headsets. Additional benefits were obtained by inserting an adjustable audio amplifier for operator use in setting levels from the headsets to meet his own preference.

From post analysis of magnetic tape recordings made at the aircraft terminal of the same PLACE modem outputs as used for the operator's headsets, it was learned that the received voice quality was similar to that observed for ground-received voice, which was also recorded on tape at the ground terminal. On those occasions when the intelligibility was poor, the cause was determined to be due to improper setting of input levels to the PLACE ground modems at Rosman or bad voice communication by the speaker.

The FAA SELCAL feature was not used by the controllers during the demonstrations. Apparently, the use of the prepared scenarios for the voice messages to and from the simulated aircraft negated the need for the SELCAL. However, the SELCAL feature was checked out several times during the tests by operators at the ground and aircraft terminals, and it performed satisfactorily. Table 2 is a summary of signal-carrier-to-noise levels of the PLACE receive channel, as measured at the aircraft terminal during the ATC demonstrations. Data for the April 3, 1975, demonstration was not recorded. It should be noted that these received signal levels are in general, appreciably higher than the minimum level of 43.0 dB Hz projected for the AEROSAT aircraft receive or "forward" channel.

Data communication at both the KC135 aircraft and the NAFEC ground terminals was considered of good quality and reliability for both aircraft position polls and text-message categories of data communications. One measure of performance of the satellite-supported ATC demonstration data link and supporting software programs can be obtained by examining the text message logs recorded at each terminal. The number of messages sent versus the number of messages received was used as a criterion for this analysis. Data transactions that occurred during known failures in the system have been screened from the data samples evaluated; therefore, the results are an indication of the efficiency of the software and the actual satellite link performance.

TABLE 2

SUMMARY OF SIGNAL-CARRIER-TO-NOISE LEVELS DURING THE ATC DEMONSTRATIONS

TEST DATE	SIGNAL-CARRIER-TO-NOISE LEVEL IN dB Hz HIGH	LOW	AVERAGE
Oct. 1, 1974	49.3	45.5	47.1
Oct. 23, 1974	51.0	46.3	48.3
Oct. 29, 1974	51.2	50.3	50.8
Nov. 12, 1974	50.8	43.1	48.3
Nov. 22, 1974	53.6	50.6	52.6
Jan. 22, 1975	50.3	48.0	48.8
Feb. 1, 1975	53.7	43.0	48.6
Mar. 21, 1975	53.3	46.0	49.1
Mar. 24, 1975	50.0	43.4	46.9

Tables 3 and 4 show the results of this analysis for the NAFEC ground/KC135 aircraft forward and return channels and the NAFEC ground/Rosman ground simulated aircraft forward and return channels, respectively. The performance of the KC135 aircraft/NAFEC ground return channel is the most variable of the four links. This is not unexpected since this link is the weaker in power budget. For a comparison of performance in a set of better balanced links (table 4), note that the average percent of received messages at the simulated aircraft terminal for the nine test dates was 91 and at the NAFEC ground terminal 89.

The results of polled data for the automatic-position communication exchanges for the nine test dates is another measure of performance of the ATC-demonstration satellite link and supporting software programs. Tables 5 and 6 show the percentage of complete polls on each test date for the NAFEC ground/KC135 aircraft and the NAFEC ground/Rosman ground simulated aircraft satellite channels, respectively. Again, the results show that the NAFEC ground/Rosman ground simulated aircraft links (better balanced in power budget) provided the more consistent performance. As can be noted from the data in these tables, the polling performance for a single-poll-only technique was considerably degraded over polling where the poll was repeated at least once.

In preparation for the demonstrations of ATC independent surveillance, a number of PLACE two-satellite position determination tests were conducted during the technology phase of the ATS-6 experiment. The purpose of these tests was to provide NASA's personnel with an actual test medium for obtaining calibration constants and perfecting the computation software. Comparative aircraft position data was obtained from the Extended Area Range Instrumentation Radar (EAIR) for tests made in the vicinity of NAFEC and the onboard INS of the testbed aircraft for tests made over the North Atlantic.

The PLACE two-satellite position determination capability was beset with a series of difficulties for the greater part of the 1974/75 ATS-6 experiment period. These difficulties mainly involved hardware and software problems. Although three ATC independent surveillance demonstrations, with the testbed aircraft in flight, were accomplished, the NASA-projected position fix accuracy

TABLE 3

ATC DEMONSTRATION DATA LINK PERFORMANCE TEXT MESSAGES--
GROUND TERMINAL/KC135 AIRCRAFT

Test Date	Number Messages	% Received Aircraft	% Received Ground
10/1/74	29		100
	28	100	
11/12/74	28		68
	23	83	
11/22/74	16		44
	13	69	
1/22/75	68		56
	44	95	
1/31/75	64		77
	34	97	
2/1/75	73		90
	53	89	
3/20/75	81		87
	51	90	
3/21/75	102		60
	57	91	
4/3/75	67		82
	37	81	
	Averaged % 9 Test Dates	88	74

TABLE 4

ATC DEMONSTRATION DATA LINK PERFORMANCE TEXT MESSAGES--GROUND TERMINAL/SIMULATED AIRCRAFT

Test Date	Number Messages	% Received Simulated A/C	% Received Ground
10/1/74	24		67
	21	76	
11/12/74	43		96
	41	90	
11/22/74	28		89
	13	92	
1/22/75	65		95
	48	96	
1/31/75	47		98
	34	94	
2/1/75	52		100
	42	91	
3/20/75	20		70
	13	85	
3/21/75	69		99
	47	98	
4/3/75	22		87
	16	100	
	Averaged % 9 Test Dates	91	89

TABLE 5

ATC DEMONSTRATION DATA LINK PERFORMANCE POSITION POLLS--GROUND/TERMINAL KC135 AIRCRAFT

Test Date	Number of Polls	% Reply 1st Poll	% Reply 2nd Poll	% Polls Complete	% Polls Incomplete
10/1/74	91	45	47	92	8
11/12/74	282	28	23	57*	43
11/22/74	629	47		47**	53
1/22/75	244	65	16	81	19
1/31/75	278	74	10	84	16
2/1/75	295	63	14	77	23
3/20/75	250	66	22	88	12
3/21/75	229	25	65	90	10
4/3/75	262	57	34	91	9
			Averaged % 9 Test Dates	79	21

* Includes % successful on third and fourth poll
** Single poll only technique used

TABLE 6

ATC DEMONSTRATION DATA LINK PERFORMANCE POSITION POLLS --GROUND TERMINAL/ ROSMAN SIMULATED AIRCRAFT

Test Date	Number of Polls	% Reply 1st Poll	% Reply 2nd Poll	% Polls Completed	% Polls Incomplete
10/1/74	35	66	31	97	3
11/12/74	254	86	4	92*	8
11/22/74	487	82		82**	18
1/22/75	301	96	2	98	2
1/31/75	290	98	2	100	0
2/1/75	278	94	5	99	1
3/20/75	227	78	19	97	3
3/21/75	142	96	4	100	0
4/3/75	553	95	4	99	1
			Averaged % 9 Test Dates	96	4

* Includes % successful on third and fourth polls
** Single poll only technique used

of 2 kilometers was never realized. However, one aspect of the ATC independent surveillance demonstration was realized; that was the implementation of the required equipment configurations, interfaces, and software modifications at the NAFEC and Rosman ground terminals for displaying the testbed aircraft position from both the dependent and independent surveillance techniques on the ATC situation display. This objective was accomplished during the last ATC demonstration flight, April 3, 1975.

U.S., ESA, AND CANADA JOINT DEMONSTRATIONS. Voice and data performance during the joint ATC demonstrations between the KC135 aircraft and the NAFEC ground terminal was similar in quality and dependability to that experienced for the U.S. dedicated demonstrations. Table 7 and 8 show data link performance results for ATC text message exchanges over the NAFEC ground/KC135 aircraft forward and return channels and the NAFEC ground/Rosman ground simulated aircraft forward and return channels, respectively. The performance of these four links during the joint demonstrations is characteristic of the results obtained in the U.S. dedicated demonstrations.

The severely degraded performance of the KC135 aircraft-to-ground link for the March 26 joint demonstration was attributed to problems with the software at the aircraft terminal. The results of the automatic position poll data communication exchanges for the FAA test aircraft and ground-terminal satellite links are shown in tables 9 and 10. Again, the performance results were similar to those of the U.S. dedicated demonstrations. The software problems at the KC135 aircraft terminal for the March 26 test date is also reflected in the percentage of complete polls, as it was in the text message performance.

In review of the data in tables 8, 9, and 10, it will be noted that there is no entry for the September 20, 1974, scheduled demonstration, the first demonstration of the ATS-6 experiment. The reason for this is that no scenarios were used. The full demonstration period was dedicated to exercising a simplified test routine in order to establish demonstration procedures at the three terminals. However, text messages and polling for aircraft position were performed with each test aircraft terminal on an individual basis for checkout and verification of the communication channels, data link terminal systems, loading and execution of programs, etc. Data entries in tables 8 and 9 for September 25, 1975, actually are not from the scheduled demonstration, but from test runs conducted that night with the Comet and Rosman terminal only.

For the September 25 test, the Comet was parked at NAFEC, and the KC135 aircraft was parked at Loring AFB, Maine, an unfavorable location for satellite communications operations from the ground because of the direction the ATS-6 L-band antenna was pointing on that date. The scheduled demonstration on September 25 was disrupted by an outage of the Rosman 85-foot-diameter C-band parabolic reflector antenna, due to a hydraulic problem. Although attempts were made by NASA personnel to substitute a backup 15-foot-diameter antenna system, communications through the forward channels only were successful. Because of the unsuccessful scheduled demonstration, NASA provided additional satellite time that night for ATC demonstration purposes.

TABLE 7

ATC JOINT DEMONSTRATION DATA LINK PERFORMANCE TEXT MESSAGES--GROUND TERMINAL/ KC135 AIRCRAFT

Test Date	Number Messages	% Received Aircraft	% Received Ground
9/23/74	4	100	100
9/27/74	6		100
	4	75	
3/24/75	40		65
	22	86	
3/26/75	88		27
	31	97	
	Averaged % 4 Test Dates	90	73

TABLE 8

ATC JOINT DEMONSTRATION DATA LINK PERFORMANCE TEXT MESSAGES--GROUND TERMINAL/SIMULATED AIRCRAFT

Test Date	Number Messages	% Received Aircraft	% Received Ground
9/25/74	16		100
	18	94	
9/27/74	4		100
	7	71	
3/24/75	22		100
	16	81	
3/26/75	47		85
	34	88	
	Averaged % 4 Test Dates	84	96

TABLE 9

ATC JOINT DEMONSTRATION DATA LINK PERFORMANCE POSITION POLLS--GROUND TERMINAL/ KC135 AIRCRAFT

Test Date	Number of Polls	% Reply 1st Poll	% Reply 2nd Poll	% Polls Complete	% Polls Incomplete
9/23/74	48	54	44	98	2
9/27/74	12	100		100	0
3/24/75	121	14	79	93	7
3/26/75	230	36	41	77	23
		Averaged % 4 Test Dates		92	8

TABLE 10

ATC JOINT DEMONSTRATION DATA LINK PERFORMANCE POSITION POLLS--GROUND TERMINAL/ ROSMAN SIMULATED AIRCRAFT

Test Date	Number of Polls	% Reply 1st Poll	% Reply 2nd Poll	% Polls Completed	% Polls Incomplete
9/23/74	23	100		100	0
9/25/74	10	70	30	100	0
9/27/74	6	83		83	17
3/24/75	214	98	1	99	1
3/26/75	116	91	9	100	0
		Averaged % 4 Test Dates		96	4

Voice-only ATC communication exchanges were conducted between the Canadian and NAFEC ground terminals. The performance was of good quality throughout each demonstration period, similar in comparison to that experienced in communications between the NAFEC and Rosman simulated aircraft terminals.

As previously indicated in table 1, the ESA Comet aircraft was actually in flight only on three of the six scheduled dates for the joint demonstrations. It was the ESA operations manager's procedure to remain on the ground after the start of satellite time for ATC demonstration tests until he was assured that the equipment and ATS-6 communications channels were fully operational and data were satisfactorily being transferred between the Comet and NAFEC ground terminal. Some problems with equipment and/or the communications channels occurred on September 20 and 25, 1975; therefore, the Comet remained on the ground for these two demonstrations. On March 24, 1975, the Comet's L-band data transmissions were off frequency sufficiently to prevent reception of the test message and polling data at the ground terminal, which again caused the Comet to remain on the ground for conduct of the demonstration.

Voice communication performance between the in-flight Comet and the NAFEC ground terminal were of good quality, similar to that experienced with the FAA KC135 aircraft. For those demonstrations when the Comet was on the ground and the equipment and communications channels were fully operational, the voice communication performance as observed at the NAFEC terminal was similar to that experienced with the Rosman simulated aircraft and the Ottawa terminals. The major difference in the performance for the two situations was attributed to the presence of aircraft background noise when the Comet was in flight. Similar performance results, perhaps even more pronounced, were evident for in-flight versus ground-based situations with the KC135.

Results of data communication performance between the Comet aircraft and the NAFEC ground terminal during the ATC demonstrations are presented in tables 11 and 12. The text messages and polling performance obtained on September 27, 1974, and March 26, 1975, (both dates when the aircraft was in flight) are considered more representative for operations with the Comet demonstration test terminal. Interface of the Comet Omega navigation system to the FAA data link system to provide automatic position reporting was not in the original joint demonstration test plans; therefore, position poll data prior to the March test dates consisted of only the simulated aircraft position reports. The required interface was designed in the interim between the ESA fall and the winter/spring campaign series and was installed when the FAA demonstration terminal was reinstalled in the Comet at the Azores in March 1975.

ANALYSIS

Based on the results of both the U.S.-dedicated and joint U.S./ESA/Canada ATS-6 experiment ATC demonstrations as well as the reaction from members of the ATC and aviation communities who witnessed the demonstrations at the NAFEC ground terminal, the ATC demonstrations were an unqualified success. Satellite-supported communications and dependent surveillance systems and techniques con-

TABLE 11

ATC JOINT DEMONSTRATION
DATA LINK PERFORMANCE-- TEXT MESSAGES-- GROUND TERMINAL/COMET AIRCRAFT

TEST DATE	NUMBER MESSAGES SENT	% RECEIVED AIRCRAFT TERMINAL	% RECEIVED COMET GROUND TERMINAL
9/25/74	28		64
	32	97	
9/27/74	10		50
	8	100	
3/24/75	--		--
	4	100	
3/26/75	35		89
	33	94	
	Averaged % 4 test dates	98	68

TABLE 12

ATC JOINT DEMONSTRATION
DATA LINK PERFORMANCE-POSITION POLLS--GROUND TERMINAL/COMET AIRCRAFT

Test Date	Number of Polls	% Reply 1st Poll	% Reply 2nd Poll	% Polls Completed	% Polls Incomplete
9/23/74	2	0	50	50	50
9/25/74	12	8	59	67	33
9/27/74	24	63	0	63	37
3/26/75	361	70	21	77	23
		Averaged % 4 Test Dates		64	36

ceptually applicable for control of air traffic in an oceanic environment were demonstrated. Voice communication, digital data communication, and automatic aircraft position reporting (dependent surveillance) through a sequential polling technique were successfully accomplished. With one exception, September 25, 1974, all ATC demonstrations planned for the coordinated ATS-6 experiment were successfully conducted. Ninety-three percent of the planned data were acquired. A first in oceanic ATC communications was accomplished on November 12, 1974, when a controller at one of the New York ARTCC oceanic sectors successfully communicated directly with the crew of the FAA KC135 aircraft, which was in flight over the Atlantic Ocean, 2,000 miles east of New York City.

The ATC demonstration was not designed, nor was it an objective of the program, to evaluate the systems equipments, techniques, or procedures employed in support of the effort. Nevertheless, the NAFEC engineers and ATC personnel involved during the course of configuring the testbed and conducting the demonstrations were able to glean many qualified technical and operational inputs that could be of value to the AEROSAT program. The following summarizes these inputs.

TECHNICAL ASPECTS.

1. As a result of the implementation and establishment of the ATS-6 ATC demonstration system, NAFEC satellite program team technical personnel developed expertise in required AEROSAT disciplines, such as, systems design, software preparation and programming, audio systems, and satellite channel analysis. Similarly, ATCS personnel of the satellite team developed expertise in the use of satellite-supported voice and data communications operations. This expertise is directly applicable to the AEROSAT Engineering and Development (E&D) program.

2. The computer chosen for the demonstration airborne system was a Varian 620/L-100. This unit was nonruggedized, but proved to be very reliable in flight. This experience suggests the possibility of utilizing a nonruggedized unit for the AEROSAT E&D program to reduce costs.

3. Performance of demonstration system installations in the KC135 and Comet aircrafts, indicated the equipment problems due to power outages, surges, and vibrations were virtually nonexistent. Variations to extremes in high and low temperatures did not influence operation or cause any permanent damage.

4. During the initial phase of the demonstrations, paper tape was used to load programs into the 620/L computers at the three test aircraft terminals. This proved to be time consuming and troublesome, because tapes often became damaged and unusable, especially at the KC135 terminal, due to limited space. To alleviate the problem in the KC135, a LINC magnetic tape system was procured and installed. Use of magnetic tape in lieu of paper tape for loading programs is recommended for the systems used in the AEROSAT program because of the many advantages.

5. L-band return channel (aircraft-to-ground) transmissions were unintentionally retransmitted from the ground via the C-band forward channel during the demonstrations. Since all L-band terminal users received the retransmitted voice, they were able to determine voice channel availability by simply monitoring the channel. This monitoring capability was not a PLACE design feature; in fact, the PLACE system L-band transmit and receive frequencies are separated by 100 MHz, and L-band terminal users can not normally hear return channel transmissions by other users. Channel monitoring in the PLACE design is provided by channel status lamps; however, this feature was not always functioning during the demonstrations, so it was not relied on as a part of the demonstration. The retransmission condition provided the L-band terminals with a "sieze-when-available-with-monitor capability" feature that was exploited for nonscenario voice message exchanges with the NAFEC and Rosman ground terminals.

The retransmission condition was found to be related to the inclusion of the NAFEC-dedicated telephone circuit termination in the satellite communications link. The telephone circuits coming into the NAFEC terminal were four-wire, while the audio switching system and equipment at the terminal were two-wire devices. The transition from the four-wire to two-wire is performed by the term set, which is a hybrid transformer circuit. Ideally, the hybrid circuit prevents all energy in the receive path from entering the transmit path. Operationally, the hybrid circuit does not totally isolate the receive voice circuits from the transmit circuits. The return energy causes no problem when the round-trip delay time is short. It becomes a problem at longer delay times, such as the signal transit times in satellite communications (see references 1 and 2). For the demonstrations, the C-band transmitter at Rosman was operated continuously; therefore, return channel voice, when introduced into the send telephone circuits, was transmitted to all L-band terminals.

Several approaches could be implemented to eliminate return-channel retransmissions if it were considered desirable, these include:

a. Installation of echo-suppression equipment on the telephone circuits.

b. Gating the C-band voice transmissions with a signal-generated push-to-talk actuation at the C-band user ground terminal.

c. Installation of four-wire switching and audio equipment at the C-band user ground terminal.

6. A major contributor to the low polling rate that existed during the demonstrations was the amount of prekey used on the header of all return-link messages.

This prekey was divided into three parts; 1 second for PLACE demodulator (phase) lockup, 0.5 seconds for PLACE modem lock, and 1.5 seconds for NAFEC terminal telephone modem lock. The latter was required because the C-band demodulator clock was used to drive the telephone modem at Rosman in an external clock mode. The C-band demodulator clock was derived from the aircraft data transmission. Therefore, the clock would be different depending on which aircraft in the demonstration was replying. Since the telephone modem at NAFEC had to

acquire bit sync on each aircraft, each return-link message had to contain bit sync. Consideration should be given in the AEROSAT E&D Program for buffering the C-band demodulator data before it enters the telephone modem. In this configuration, the internal clock of the telephone modem can be used to shift the data out of the buffer, and synchronization can be maintained. The other major contributor to the lengthy prekey, 1-second time interval to lock up the PLACE demodulator on the return-link transmission was to account for the aircraft's Doppler frequency effects. For the AEROSAT E&D program, consideration should be given to storing each aircraft's Doppler frequency by the ground terminal software.

7. Because of the ATS-6 ATC demonstration software design, a considerable amount of processor time was required in calculation of the BCS polynomial used for message parity checks. Consideration should be given in the AEROSAT E&D program to implementing the parity check feature with hardware or firm ware.

8. The demonstration system design did not include provisions for computer-controlled access to the voice channel. Lack of this feature had no detracting affect on the demonstration, since user interference on the voice channel was minimized through use of scenarios wherein messages from each terminal were transmitted in a predesignated time slot. However, it was believed by all the participants that a positive-access channel technique would be a desirable feature.

9. Voice channel reception at the KC135 aircraft demonstration terminal was periodically affected by short-term signal variations from the norm. These variations were attributed to aircraft turn maneuvers and antenna pattern effects which were contributed by the ATS-6 and aircraft experimental L-band antennas. Only the voice channels were observed to be notably affected by these signal variations; reception of data communications appeared normal at these times. Carrier-to-noise signal levels measured during the demonstration indicated that the average level was well above 43.0 dBHz, which is the minimum value projected for the AEROSAT forward channels. In view of the existence of these conditions as observed in the demonstrations, consideration should be given in the design of the AEROSAT system to a thorough examination of the minimum carrier-to-noise signal level required for good quality voice-channel communications.

10. The ATS-6 satellite simulator provided by NASA at the Rosman ground station proved to be a very valuable test device for the ATC demonstration, particularly in the checkout readiness phase. It would be advisable to have a similar test device for AEROSAT.

OPERATIONAL ASPECTS.

1. Although the ARINC 586 format is flexible and can be expanded, the intricacies of this format should be transparent to the user of the data communication link. Thus the user should have a simplified format for sending messages with a default condition to the most used state. The usual technique implemented to produce default formatting is to have the main fields followed

by one or more optional fields. For example: ACID, MESSAGE, (OPT 1), (OPT 2), where ACID is the aircraft identification and MESSAGE is a data link message for this aircraft. If no entries are made in the optional fields, the message is interrupted as routine priority and addressed to the aircraft cockpit display unit. Entries in the optional fields can change these defaults. Defaults reduce controller workload for the most used conditions.

2. On occasions when the demonstration controller sent two data messages to a particular aircraft, both of which could be appropriately answered by a "Roger" or "Unable". If the return was indeed a "Roger" or "Unable", it was difficult for the controller to correlate the answers and questions. This type of problem requires further investigation in the AEROSAT E&D program.

3. The demonstration polling software did not provide for poll interrupts for urgent messages, which was considered a disadvantage. Additionally, it would have been desirable for the controller to generate an out-of-sequence poll for return-channel messages. This option could have been used when a reply to an ATC directive was needed before the normal poll interval for that aircraft.

4. The original version of the demonstration polling software had a feature whereby the aircraft returning a preselected number of NAK's (no acknowledgement) was dropped from the polling list. This feature was unacceptable and was later disabled. The original software also had a feature whereby the aircraft returning a NAK was repeatedly polled for a period of time, excluding the polling of other aircraft in the system at that time. This feature was disabled for the general polls, since an aircraft terminal having data link software or equipment problems could tie up the entire poll. Additionally, allowing variable length messages on the main polling channel proved to be undesirable, since it was necessary to wait a lengthy period before polling the next aircraft, which drastically reduced throughput. This situation occurred in the ATC demonstration, because there was only one data link channel available. A preferable implementation of the satellite data link would be to have a second data channel for variable length message replies.

5. During the demonstrations, the position reports were listed on the teletype as they arrived at the ground terminal. This procedure proved to be unnecessary and of no value to the demonstration.

6. The Hazeltine 2000 CRT display at the NAFEC ground terminal was used in the teletype mode, wherein the lines are scrolled from bottom to top. If a moderate amount of data was entered on the keyboard, needed information was quickly lost off the top of the display. Return-link messages were also displayed on the Hazeltine, causing scrolling of the ATC's entries. A form-fill-out scheme using a core image of what is contained on the controllers data display is essential for the AEROSAT E&D program.

7. Initialization of both the ground and airborne software for the demonstration was a very involved process. Long lists of console commands had to be entered each time the program had to be restarted. Since these "configuration" commands were seldom changed, in retrospect it is now believed that the software should have been in a standard configuration default state as soon as it was read into the computer from the magnetic tape. In addition, flight plans should have been prestored. Consideration should be given to using a similar arrangement in the software for the AEROSAT E&D program.

8. The cockpit display unit developed for the ATC demonstration had a unique data entry format which featured a standard 10-button keyboard configured with three letters and one number on each key. The software was designed such that standardized message formats, such as flight-level reports, position reports, channel requests, etc., could be entered with a minimum of buttons. Consideration should be given to the use of a similar format for the AEROSAT E&D program.

9. The experience from preparing programs for the ATS-6 ATC demonstration elicits the following guidelines for software design in the AEROSAT E&D program:

a. It is more cost effective to purchase additional core than to pay programmers to condense software.

b. The software should use no programming tricks, even if this results in the expenditure of additional core and central processor time.

c. Programs written in assembly language are very difficult to debug and modify.

10. During the conduct of the ATC demonstrations, many potential problems applicable to the use of data communications in the oceanic environment were uncovered. For example, problems were noted in correlating forward and return messages, maximum poll cycle time, message accountability, overly complicated operating procedures, and repeating messages that failed to get through. Although some of these problems were related to faulty software, most were caused by design philosophy.

11. The ATC demonstrations pointed out the need for the airborne terminal user to have assurance that the data communication equipment is working. For example, some type of indicator (light, etc.) that would indicate the data link system is receiving polls even though they are not addressed to that particular terminal.

CONCLUSIONS

It is concluded that:

1. The ATS-6 experiment ATC demonstrations were an unqualified success and the objectives of the program were accomplished.

2. NAFEC engineering and ATC personnel involved in the conduct of the ATC demonstrations obtained technical and operational expertise that will be a valuable asset to the AEROSAT E&D program.

3. Results of the ATC demonstrations provided qualified technical and operational expertise that will be a valuable asset to the AEROSAT E&D program.

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APPENDIX A

DESCRIPTION OF NASA POSITION LOCATION AND AIRCRAFT COMMUNICATIONS EQUIPMENT (PLACE)

The NASA position location and communications equipment (PLACE) is a computer-based system using three ground terminals and a mobile transponder. Rosman, North Carolina, is the primary ground terminal, with the other ground terminals at Mojave, California, and Santiago, Chile. The PLACE system provides ATS-6 satellite-relayed functions of voice and data communications, ranging, and system control.

PLACE ground equipment provides seven separate communications channels three voice channels, three data channels, and a surveillance and ranging (S&R) channel. Voice communication is accomplished using adaptive narrow-band frequency-modulated signals. The audio is pre-emphasized (6-dB/octave) and fed through a 12-dB clipper prior to modulating the carrier. Data communication is accomplished using differentially encoded coherent phase shift-keyed (DECPSK) signals. The data rate is normally 1200 bits-per-second (b/s). S&R and systems control communications are accomplished using a 600-b/s data link signal combined with range tones for transmission on a single carrier. The modulation technique used is referred to as quadrature modulation. The range tone modulation is double-side-band, suppressed-carrier amplitude modulation. The data link signal is applied as a quadrature component on the same carrier using DECPSK modulation. The PLACE ground equipment provides and accepts 70-MHz intermediate frequency (IF) signals for interface to the Rosman station C-band transmitters and receivers, respectively.

PLACE airborne equipment consists of three units; L-band receiver/transmitter (R/T) unit, IF modem unit, and R/T power supply unit. These units in conjunction with an L-band antenna provide a two-way communications capability of one voice channel, one 1200-b/s data channel, and one S&R channel. In operation, the forward-link L-band signals are amplified, filtered, and down-converted to 70 MHz in the R/T unit and then sent to the modem. The modem uses a threshold extension frequency modulation (FM) demodulator to extract the voice signal. The 1200-b/s and 600-b/s S&R data are coherently demodulated using Costas loop demodulators. Integrate and dump filters are used for detection and decoding. The 600-b/s data are further processed in the modem using synchronization coding provided in the forward link transmission to extract the appropriate order-wire data, i.e., S&R time slot assignment, voice, 1200-b/s data channel status, and other PLACE system control commands. Return-channel voice, 1200-b/s data, and 600-b/s S&R data are modulated on carriers using modulation techniques similar to those described for the PLACE ground equipment. The signals are linearly combined and fed to the R/T unit at 60-MHz IF frequency. The R/T unit up-converts to L-band frequency and amplifies the signals for transmission to the ground terminal via the ATS-6.

As indicated above, the PLACE S&R channel contains two types of information; ranging tones which are used for position determination of the mobile terminals and a 600-b/s data link system which is used as an order wire. The range tones consist of four sine waves at 8575, 8550, 8400, and 7350 Hz which are linearly combined and simultaneously transmitted to the airborne terminal/mobile from the ground terminals via two paths, ATS-5 and ATS-6. Range tone signals over the ATS-5 path are received at the airborne terminal using a separate L-band

antenna and receiver. The airborne terminal/mobile retransmits the tones back to the ground terminal on the S&R channel via ATS-6 using time multiplex to separate tones as received over the two forward-channel paths. The signal flow described differs from the transmission directions of the original PLACE design. The original design utilized one satellite in the forward direction to the mobile, with signal return to the ground terminal via two satellites. The modified signal flow was selected by NASA because of an ATS-5 L-band receiver malfunction. Aircraft altitude required to compute the aircraft's position is sent to the ground on the 600-b/s S&R data channel. Range is determined by measuring the phase shift in the tones, which is a result of the round-trip transmission. A central processor unit at the ground terminal performs the position fixing computation and outputs the data in latitude/longitude coordinates.

The 600-b/s data channel uses a time-division multiple-access scheme to avoid interference between multiple users operating on the same S&R channel. The forward-link message structure from the ground terminal is central-controlled to provide a time-ordered system called an order wire. In operation, each user is assigned a different time slot for transmission on the return link. The time synchronization signal is provided in the forward-link message. Thus, each user transmits sequentially with no mutual interference.

The S&R order-wire message structure has 320 transmission time slots of 0.2 seconds ground-to-air and 0.16 seconds air-to-ground. It can service approximately 250 aircraft. In addition to the above functions, the design has provisions (1) to inform users as to which voice and data channels are in use, (2) to permit random or unscheduled entry of an aircraft into the system, and (3) to give specialized handling to an aircraft declaring an emergency situation. Since ATS-5 is a spinning satellite, the original order-wire timing format is modified to operate in synchronization with the periodically available return-channel, earth transmit window.

Attention is called to the following references for further details on the PLACE system.

REFERENCES

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3. <u>Handbook of Operating and Maintenance Instruction for PLACE Airborne Communication Equipment</u>, Bell Aerospace Report No. 6203-954002, Contract No. NAS5-21120.

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APPENDIX B

DESCRIPTION OF NAFEC AND ROSMAN TERMINAL OPERATIONS AND INTERFACE DETAILS

ROSMAN TERMINAL.

The NASA Rosman, North Carolina, satellite-tracking station was used during the ATS-6 experiment ATC demonstrations to house the FAA simulated-aircraft terminal.

Three dedicated telephone circuits were provided between NAFEC and the Rosman tracking station for the transmission of voice and data. A switching network at NAFEC enabled rapid reconfiguration of the function of each circuit. During the joint demonstrations held in conjunction with the European Space Agency (ESA), two circuits were utilized for voice and one for data. Coordination with Rosman from NAFEC was accomplished via the SCAMA network through Goddard Space Flight Center. During the FAA demonstrations, one circuit was used for data, one for voice, and one for coordination with the FAA representatives at Rosman.

The data transmissions necessitated the use of data modems at both locations to make the digital data suitable for the telephone circuits. Three Telco data modems at each terminal station, each with selectable bit rates of 1200 or 2400 bits-per-second (b/s), gave the system the capability of up to three simultaneous data channels. In order to tie the telephone circuits into the NASA PLACE C-band transmitter and receiver equipments, two interface patch panels were provided. These two panels, designated interface units 1 and 2, performed the proper signal conversions, squelch, amplification of voice, and signal routing within the building.

The C-band patching for the ATC demonstrations is diagrammed in figure B-1a and B-1b. A general overview of the data and voice signal flows at the Rosman terminal is as follows: Data going from NAFEC to Rosman were taken from the receive side of the telephone circuit, in this case telephone line 94, and patched into the receive input of one of the Telco modems. There the data were demodulated, and a clock signal, which was synchronous with the data, was generated. This synchronous transmission of data was achieved by sending, prior to the data, a periodic waveform called "prekey" which enabled the receiving modem to synchronize its clock with that of the transmitting modem. The time duration of prekey needed for the Telco modems to lockup was approximately 0.5 second with a worst-case time of 1.2 seconds. Once the data and its associated clock left the Telco modem, they were patched into "RS-232 IN L," a bipolar-to-differential converter located in interface unit 2. There the RS-232-formatted signals from the modems were converted to the differential signals, required by the PLACE equipment. Leaving the differential outputs, clock and data were patched into "SEND DATA 1," where they were transferred via shielded, twisted pair to "SEND DATA 1" on interface 1. From there, the data and clock signals went to "ATS- XMIT DATA 1," where they entered the PLACE equipment for C-band transmission to the satellite. Also these signals went to "DATA ENCODERS," where the data and clock were Manchester encoded, with the output of the encoder patched to "RECORDER INPUTS 5" for recording on an Ampex FR-2000 seven-track recorder. This was the flow of data from NAFEC to Rosman and into the PLACE equipment to be forward-linked to the

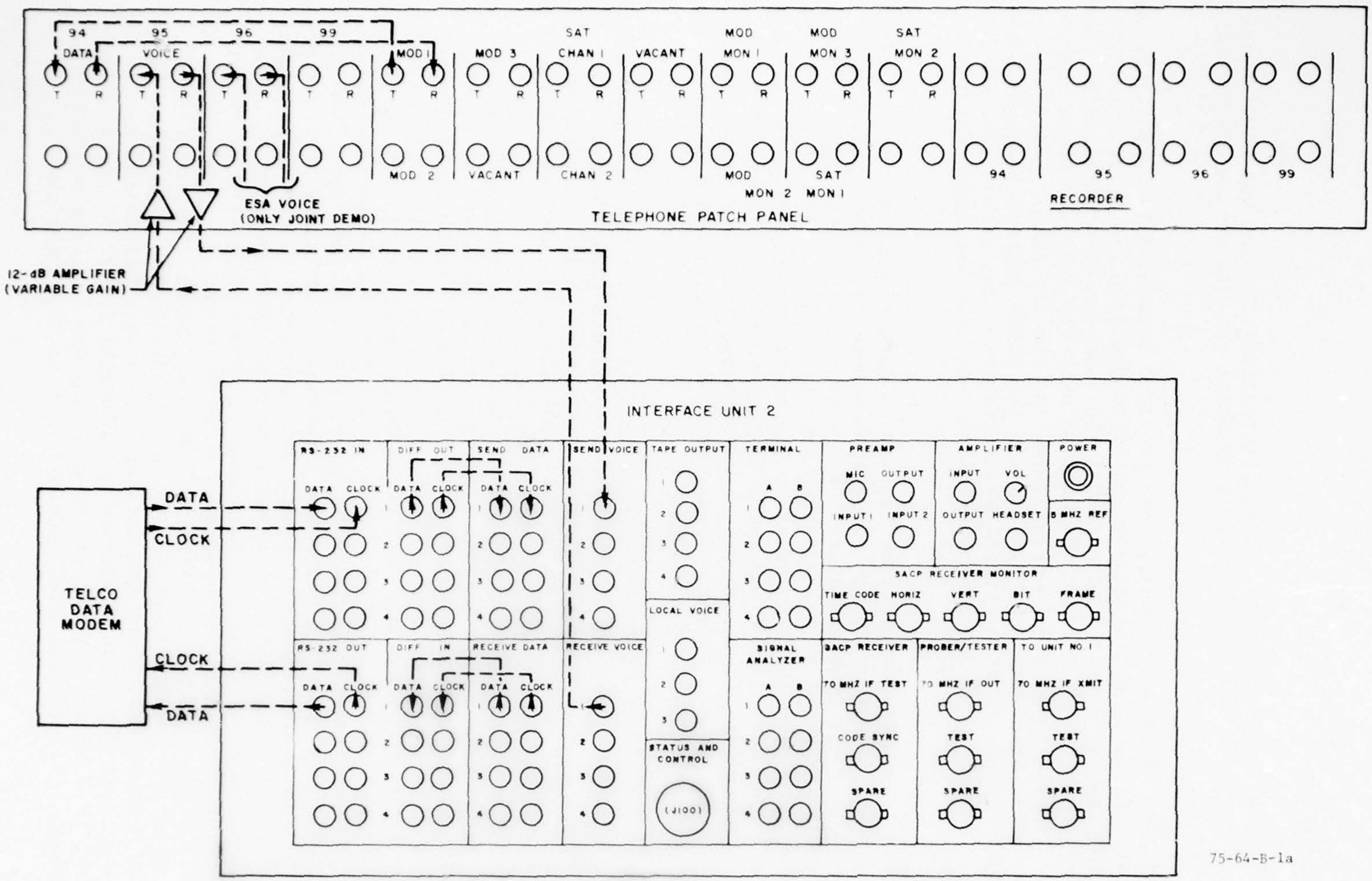

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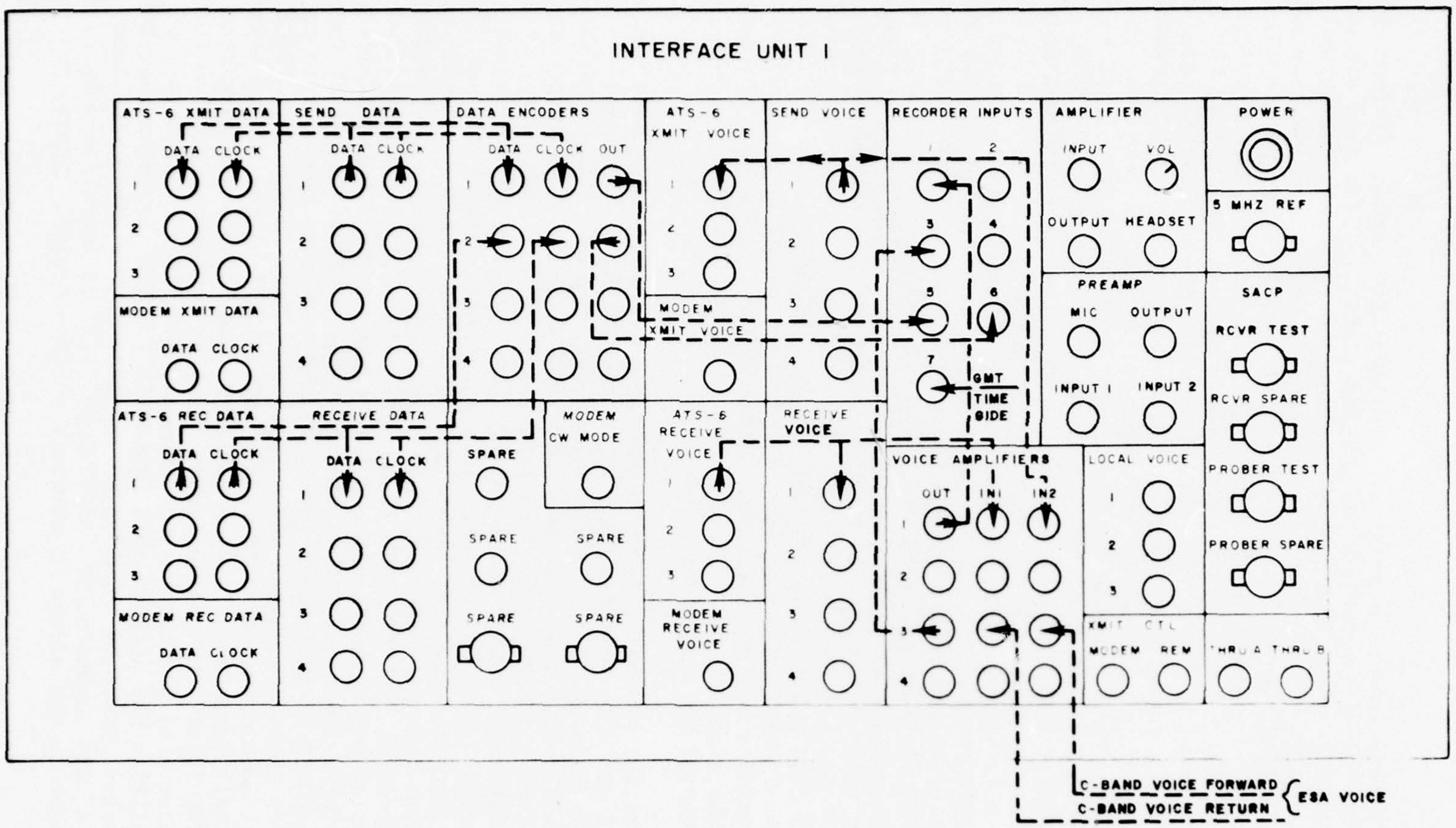
FIGURE B-1a. PLACE C-BAND CABLE PATCHING CONFIGURATION FOR ATC DEMONSTRATIONS TELEPHONE PATCH PANEL, INTERFACE UNIT 2 AND TELCO DATA MODEM



75-64-B-1b

FIGURE B-1b. PLACE C-BAND CABLE PATCHING CONFIGURATION FOR ATC DEMONSTRATION INTERFACE UNIT 1

satellite. The return-link data from the satellite were handed off from the PLACE equipment at "ATS-6 REC DATA 1" on interface unit 1. The data and clock went to "DATA ENCODERS 2" for Manchester encoding and then into "RECORDER INPUTS 6" for recording. They also went to "RECEIVE DATA 1," where they were transferred by shielded, twisted pair to "RECEIVE DATA 1" on interface unit 2. From there, they were patched into "DIFF IN 1," where both signals were transformed from differential to bipolar. The bipolar signals came out of "RS-232 OUT 1" and were connected to the Telco modem inputs. The modem then modulated the data, and a patch cord connected from "MOD 1" transmit to "94" transmit on the telephone patch panel allowed the modulated data to be sent over the telephone circuit to NAFEC. Voice signals coming from NAFEC were taken directly from the telephone patch panel at "95," received, and patched into "SEND VOICE 1" on interface unit 2. It was then sent over shielded, twisted pair to "SEND VOICE 1" on interface unit 1. There it was patched to "ATS-6 XMIT VOICE 1," the PLACE input for forward-link C-band voice modulation. Also the voice signal went to "VOICE AMPLIFIERS 1; IN 1"," a summation amplifier. Return-link C-band demodulated voice from the PLACE equipment was handed off at "ATS-6 RECEIVE VOICE 1," where it was sent to "RECEIVE VOICE 1" and "VOICE AMPLIFIERS 1 IN 2." The output of the summation amplifiers was patched to "RECORDED INPUT," which enabled both the forward-link and return-link voice to be recorded on one track. "RECEIVE VOICE 1" was connected directly to "RECEIVE VOICE 1" on interface unit 2, where it came out and was patched into the telephone line "95" transmit and was received at NAFEC. Because of varying voice signal levels from both the telephone circuits and the satellite, variable gain amplifiers were used to obtain a usable signal level. These units amplified the voice signal just as it left or entered the telephone patch panel.

The ATC demonstration simulated aircraft terminal at Rosman also made use of interface unit 1 and 2 to obtain access to the L-band PLACE equipment, as can be seen in figure B-2a and B-2b. Differential data and clock from the simulated aircraft data link computer was patched into "SEND DATA 2" on interface unit 2 and was transferred to "SEND DATA 2" on interface unit 1. From there, it was patched into "MODEM XMIT DATA," which was connected to the PLACE airborne modem data modulator input for transmission on L-band to the satellite. Data which the PLACE airborne modem at Rosman demodulated were sent to "MODEM REC DATA" on interface unit 1. Data and clock were sent from there to "RECEIVE DATA 2" and then on to "RECEIVE DATA 2" on interface unit 2. The data then reached its destination by being patched from there to the simulated aircraft data link computer's input. Voice signals from the simulated aircraft terminal went into "SEND VOICE 2" on interface unit 2, and were then transferred to "SEND VOICE 2" on interface unit 1 and were patched into "MODEM XMIT VOICE" to be transmitted over L-band by the PLACE modems and input 1 of the second voice-summing amplifier. Voice signals demodulated by the PLACE modem were sent to "MODEM RECEIVE VOICE" on interface unit 1, which was patched to "RECEIVE VOICE 2" and input 2 of the second voice-summing amplifier. The output of the summing amplifier was patched into "RECORDER INPUT 2" in order that L-band transmit and receive could be recorded on one track. The signal fed into "RECEIVE VOICE 2" was connected to "RECEIVE VOICE 2" on interface unit 2, where it then went to the simulated aircraft audio circuits. Status control

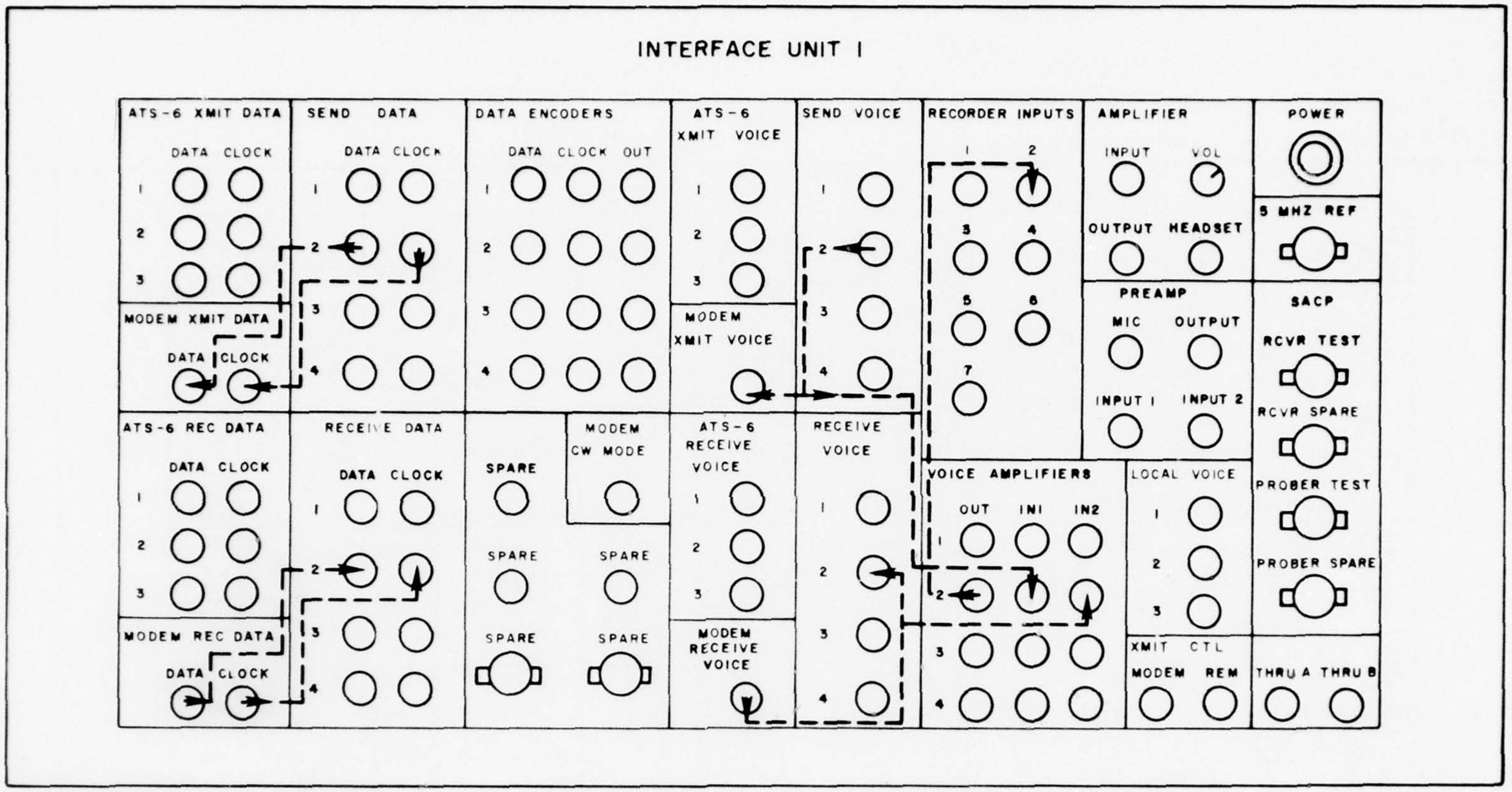


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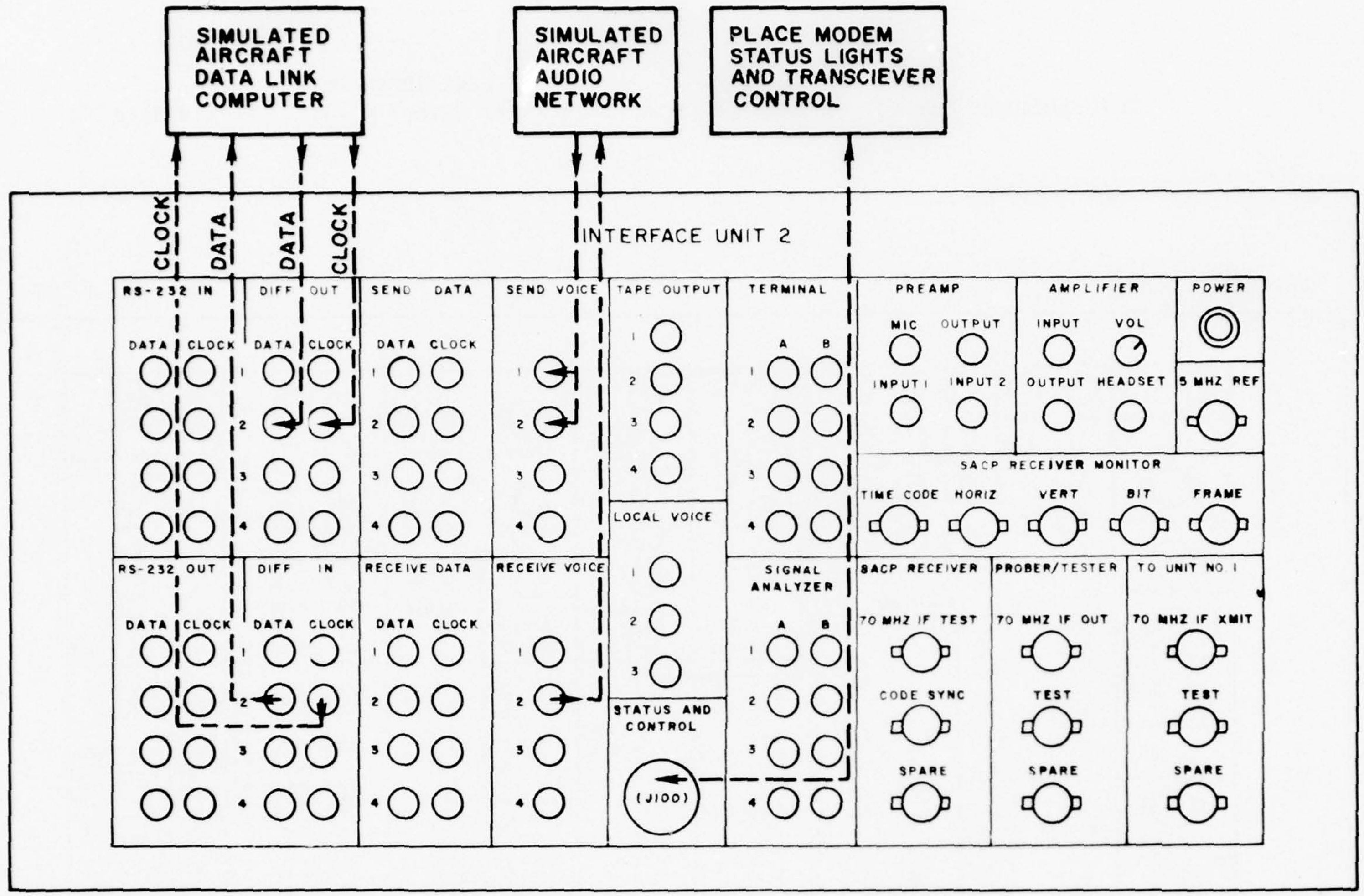
FIGURE B-2b. PLACE L-BAND CABLE PATCHING CONFIGURATION FOR ATC DEMONSTRATION INTERFACE UNIT 1



75-64-B-2a

FIGURE B-2a. PLACE L-BAND CABLE PATCHING CONFIGURATION FOR ATC DEMONSTRATIONS INTERFACE UNIT 2

signals were also taken from the PLACE airborne modem by a multiconducter cable to interface unit 2 at "STATUS AND CONTROL." They were then routed from there to the simulated aircraft for display and transceiver control.

The three test aircraft terminal data link computers (the Rosman, the KC135, and the Comet) received either data or idle code (1-0-0-), at all times, thereby maintaining synchronization with the NAFEC ground computer. The ground computer could not, however, maintain lock with all three mobile units because of frequency changes due to the Doppler effect. Before each air-to-ground data transmission, a series of three different prekeys was necessary to lock up the system. The first prekey locked the receiver at Rosman, the second locked the PLACE ground modem, and the third locked the Telco data modem at NAFEC. The time duration of each prekey could be modified by a console command at the test aircraft terminal. A total time of 1 to 1.5 seconds was needed to lock all three equipments.

Minor modifications to the patching network was necessary during the joint ATC demonstrations involving ESA. ESA required a telephone line to the NAFEC ground terminal to connect the air traffic controllers at NAFEC to their time division multiplex system (TDM) voice transceiver at Rosman. Also a voice-summing amplifier on interface unit 1 was connected so as to monitor their forward-link and return-link voice, sum it, and record it on channel 3 as shown in figure B-1b.

During FAA demonstrations when the KC135 was in an acceptable attitude for communications with ATS-5, two-satellite position determination data were provided by one of Rosman's three PDP-11-20 computers. The FAA provided a 1200 b/s clock from one of the Telco 205B modems to the PDP-11-20 current-loop interface to clock the data from the computer. To make the current-loop interface compatible with the 25B modem, an RR700 solid state repeater was provided for the conversion of current-loop data to Electronic Institute of America (EIA) Standard RS 232 A format. The modem was patched to the telephone circuit from modem transmit to the line transmit for one-way data transmission to NAFEC. Coordination between NAFEC personnel and FAA personnel at Rosman was also accomplished via the SCAMA network during tests when all three GDA telephone circuits were utilized for the test.

During conduct of the dedicated FAA and joint demonstrations, the data link was monitored at Rosman. An oscilloscope was utilized to monitor the signals at the RS 232 "DATA IN" and "DATA OUT" of interface unit 2. This monitoring provided a visual cue to the operation of the data link by displaying the forward-link polling and the corresponding response from the appropriate mobile. The monitoring capability gave great insight into the operation of the data link and facilitated troubleshooting when the link was inoperative. Three specific instances when the monitoring proved valuable were (1) verification of incorrect prekey from mobiles, (2) loss of data caused by incomplete telephone circuit's, and (3) failures of the PLACE demodulator to lock on return-link data.

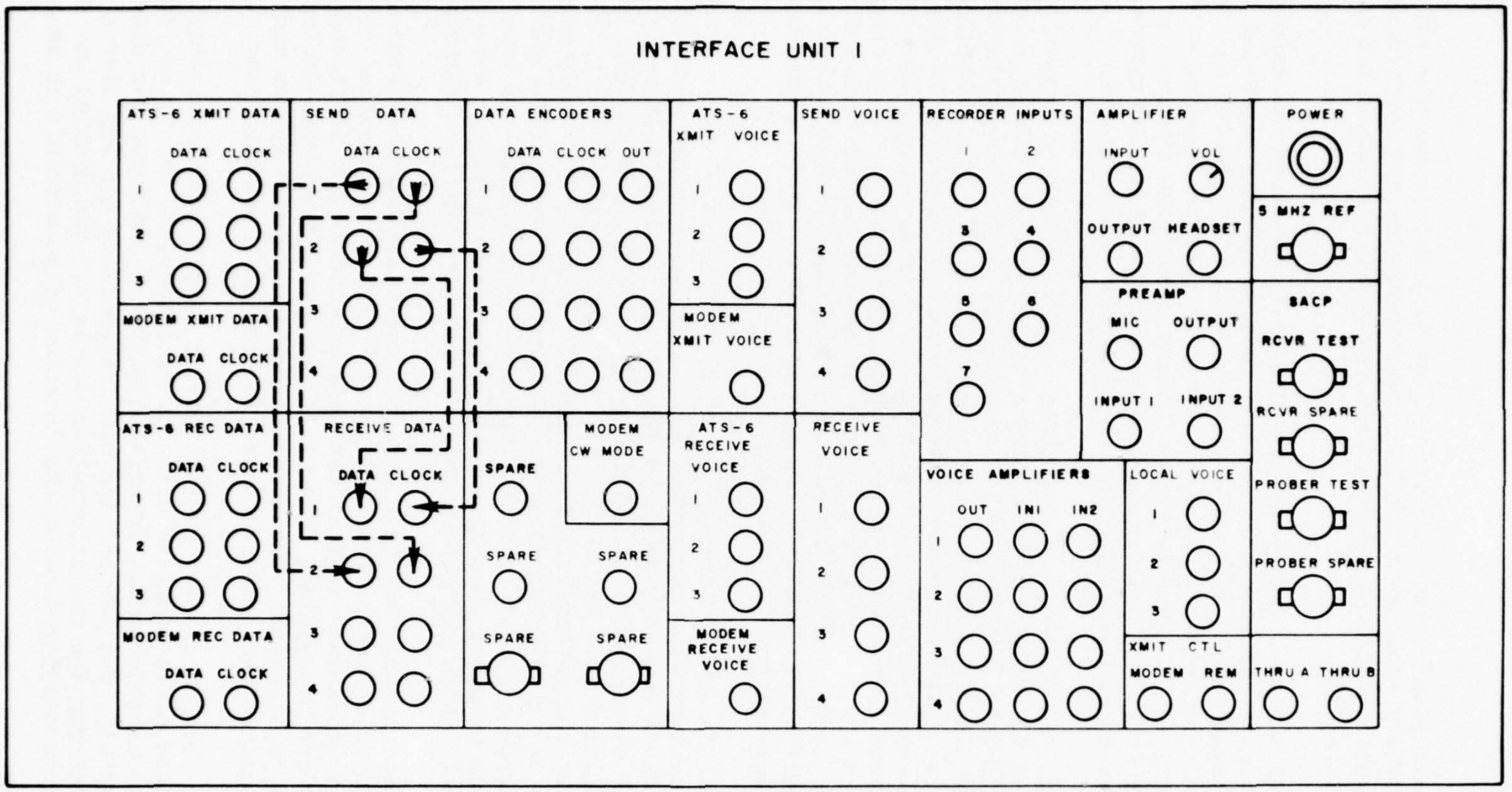
Pretest checkout of the NAFEC computers, the phone circuits, and the interfaces at Rosman was preformed through the use of the satellite simulator at Rosman. This simulator modulated voice and data to the baseband frequency of 70 MHz, demodulated it, and added noise, which could be varied, to the signals. This served to check out the entire system under normal conditions, with the exception of the satellite and C-band modulation and demodulation. Another pretest checkout used was to patch the data coming from NAFEC directly into the simulated aircraft data link computer and send it back to NAFEC. This pretest patching was done at interface unit 1 as shown in figure B-3. Interface unit 2 maintained normal patching for this pretest.

NAFEC TERMINAL.

The NAFEC ground terminal used for the ATS-6 experiment ATC demonstrations was located in building 19. The terminal housed the required computers, equipments, displays, and interfaces to support the operation of the ATC oceanic-type positions for the demonstrations.

Audio switching was performed at four locations in the terminal, at the telephone circuit control panel, and at each of three controller positions. All switching was controlled by keysets which contained pushbuttons with integral indicator lights. The telephone circuit control panel controlled the configuration of the dedicated telephone circuits to the Rosman terminal for voice or data communications operations, selection at the NAFEC terminal, and which circuits would be used by the controllers for voice communication. The panel also contained the provisions for an operator to access any of the dedicated circuits for voice communication from the panel position as well as the patching of demonstration-associated telephone calls through FTS or direct dial circuits to the ATS-6 voice channels via the dedicated telephone circuits. Controller position keysets were configured so that the controller could access any of the telephone circuits that where configured for voice communication at the telephone panel. The switches that controlled this function were self-locking with manual unlock control. Four nonlocking pushbuttons were provided at each controller position for signaling purposes. One button controlled a ring signal to the demonstration telephone patch panel at the Rosman terminal. The three remaining pushbuttons controlled the selection of a unique audio frequency available from the FAA SELCAL transmitter units, also located at the NAFEC ground terminal, which was applied to the telephone circuits in use by the controller. Similar capabilities of circuit access, ringing, and switching functions were available at the telephone patch panel.

Recording of voice communication at the NAFEC ground terminal was provided through a recorder connect module interfaced to each dedicated telephone circuit. The module functioned to ensure isolated two-way recordings of all communications on the telephone circuit. Each module was interconnected to a separate recording channel of an Ampex FR-100 A recorder unit. Universal time, provided by a synchronous time code generator, was recorded on a separate channel for postcorrelation purposes. Isolated speaker/amplifier units with ON/OFF and LEVEL control functions were also connected to each dedicated telephone circuit to provide for group monitoring of the voice communication on the circuits.



75-64-B-3

FIGURE B-3. PRETEST CABLE PATCHING CONFIGURATION FOR ATC DEMONSTRATION

A breakout box installed between the model 205B data modems and the 620/f data link computer provided convenient oscilloscope monitoring and sampling points for all data communication exchanged between the NAFEC and Rosman ATC demonstration ground terminals.

The FAA SELCAL was a modest design selective-call system that was assembled from available single-frequency transmit and receive units. Employing this system, the controller could operate a pushbutton at his position and cause a call-indicator light to illuminate and an aural alarm to sound at a particular test aircraft terminal. Either or both of these indicators alerted the operator at the terminal that the ground terminal controller required the operator to contact him via voice communication on the satellite voice channel.

The FAA SELCAL system consisted of the three single audio-tone transmitters installed at the NAFEC ground terminal and a tone receiver located at each of the three test aircraft terminals. The tone signals from these transmitters progressed through the ATC demonstration system along the same transmit/receive paths described for satellite voice communication. The receiver at each test aircraft terminal was transformer-coupled to the receive-audio output of the PLACE airborne modem. The receivers contained amplification, filtering, and detector circuitry which was fixed-adjusted to respond to one tone and reject all others; thus, each receiver (or test aircraft) had its own unique address. This modest but effective SELCAL system served to demonstrate a SELCAL operation using satellite-supported voice channels.

The ATC demonstration ground terminal equipment consisted of the two Varian 620/f and 620/i minicomputers with associated input and output (I/O) peripheral equipment. The 620/f computer provided 32k of memory, 16 bit words and a cycle time of 750 nanoseconds. Connected to the 620/f was a teletype (TTY) 10 b/s and a Hazeltine 2000 CRT device with an I/O rate of 1200 b/s, both of which were used by the controllers to initialize control, and send, and receive messages on the ATC demonstration system. The operational software programs were stored and read in on the upper nine-track magnetic tape unit; the lower unit was used for logging all the data link messages. Both units operated at 22 1/2 inches per second and read 800 bits per inch magnetic tapes.

The data link messages from the test aircraft terminal, which arrived at the ground station in an analog form at a 1200-b/s rate, were converted by the telephone circuit modem into digital form and applied to the 620/f computer for verification and processing. The 620/f computer system also included a high-speed paper tape reader. The above-described computer system made up the data communication and control center for the ATC demonstrations.

A second system, the ATC display system used to support the demonstration, was composed of the 620/i computer with 32k of memory, 16 bit words, and a cycle time of 1.8 microseconds. Interfaced with the 620/i was the display processor unit (DPU). The DPU had its own instructions and was also a small minicomputer which ran the two information displays. One display was normally used as a situation display showing the location of an aircraft in relation to

a latitude/longitude grid. The other display contained the tabular information on the aircraft such as flight level, speed, position, etc. The displays had a 50-cycle refresh rate.

The situation display console had a 30-button keyboard and a pushbutton lightpen associated with it. Certain ATC functions were programmed for each key and also for the lightpen in the ATC demonstration to assist the controller in carrying out his function more effectively. A TTY, which had a 10-b/s transfer rate, was connected to the computer to control input information on the aircraft in the system and output error information for the controller.

The 620/i computer system also contained a high-speed paper tape punch which was used to make history tapes of any events that took place in the system. The history tape was a record of all input from the TTY to the computer and any input from the display keyboard or lightpen to the computer so that at some later date a replay of the situation could be reproduced.

Also connected to the 620/i was a minimagnetic tape unit with two tape drives. This unit was used for operational program input and software development. These minimagnetic tapes were blocked so that the computer was able to address individual blocks on the tape in a nonsequential manner. In addition, the 620/i computer system contained a high-speed paper tape reader for routine tasks.

Between the two described computer systems was a 16-bit, two-way parallel hardware interface (Varian E1499 controller) which allowed the computers to transfer data at rates up to 250,000 words per second. This interface was used in the data communication operation to send aircraft position information from the communication computer to the ATC display computer and associated displays. The 620/f software passed 43 ARINC 586 formatted data bytes, including the start-of-heading and the end-of-text parts of the message. The message contained aircraft identity, latitude, longitude, and altitude.

Figure B-4 shows the data communication information flow at the ATC demonstration ground terminal. The 620/f computer software controlled the use of the data circuits at the NAFEC interface. The software parameter controls were initially set by the controllers at the beginning of each demonstration but could be changed as required during the demonstration.

The polling technique provisions used in the ground software caused the test aircraft terminal software to be in a standby status for a poll from the ground, giving the controllers complete control of the satellite data link communication system. As indicated previously in this report, there were two different kinds of polls; a general text poll and a position poll. For a general text poll, the ground software would check to determine if the time was appropriate to begin the polling cycle. If it was, it would then go to the aircraft table, pick up the first aircraft, and transmit a general text message to that aircraft. The ground system would then wait several seconds for a response from that aircraft. If it received a response, it would then poll the next aircraft

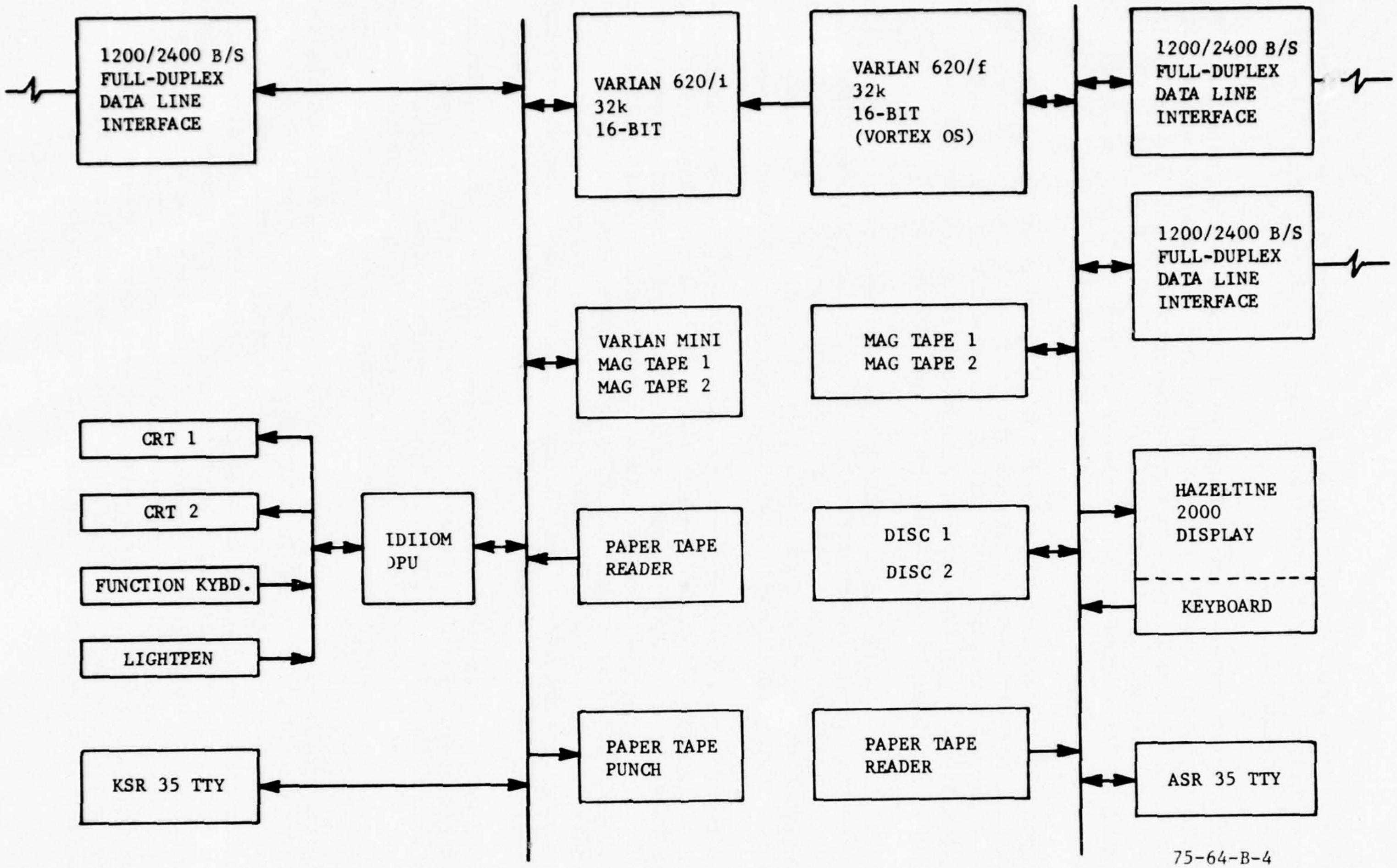


FIGURE B-4. DATA INFORMATION FLOW DIAGRAM ATC DEMONSTRATION

in the table; if it did not, then it would repeat polling the same aircraft for a preselected number of times before it printed a message to the controller stating the results of that poll, and then it would go to the next aircraft in the table and repeat the procedure. This polling procedure was continued until every aircraft in the system was polled. The general text polling cycle was made every 60 seconds. A similar procedure was used for the position poll, except the ground would send a request for position message in the appropriate format and wait for the position information from the addressed aircraft. The position poll cycle was made every 120 seconds.

At the test aircraft terminal, the Varian 620/L computer would wait until the ground polled, and when it was a general poll, it would either acknowledge the poll or if it had a message from the pseudopilot it would send it down to the ground. If the poll received was a position poll, the computer would automatically switch to either the INS or the Omega system (depended upon which system the aircraft polled was using) for the position data and then send it to the ground. It should be noted that one demonstration was conducted using a single poll technique; i.e., proceeding to the next aircraft when no return message, acknowledgement, or position information was received in response to the single poll. The ATC demonstration data link system normally had about 10 aircraft in the polling list, of which 1 to 2 were live aircraft and the remainder simulated. The major difference between a live and simulated aircraft was that the position information on a live aircraft came from its navigation system computer; whereas, the position information from the simulated aircraft came from a preplanned flightpath programmed into the 620/L data link computer.

A typical ATC message exchange between the controller and pseudopilot was as follows: The controller would type a message on the Hazeltine 2000 CRT device keyboard according to a certain format. The message would then be inputted into the Varian 620/f computer and stored in the main buffer. At the next polling cycle, the message would be sent to the addressed aircraft. The ground system would wait a prescribed length of time for an acknowledge message to assure that the message sent to the aircraft terminal was received. At the test aircraft terminal, the forward-link message would be inputted to the 620/L computer, where it would be processed and outputted to either a cockpit display unit or the pseudopilot CRT/keyboard device for display.

When the acknowledge message was received at the ground terminal, it was inputted to the 620/f computer, where it was matched with the forward-link message, and the poll to the aircraft would be complete for the polling cycle. On the next polling cycle, 60 seconds later, a default message would be sent to the test aircraft terminal asking if there were any return-link messages. In the interim, the pseudopilot had inputted a message on his cockpit display unit or the CRT/keyboard device answering the request.

All messages sent from the aircraft terminals to the ground terminal included a code which routed the message to the proper ground output device. When the message was a general-text ATC message, it would be routed to the Hazeltine CRT device for display to the controller at that position. It

would also be logged on a nine-track magnetic tape recorder for offline print-out. If the message was a position report, besides the above output devices, it would also be routed to the Varian 620/i computer. The 620/i computer, plus associated peripherals, was used to process the position reports and to update the tabular and situation displays which were being controlled by the DPU. The controller situation display was updated as a result of each poll; therefore, he always saw displayed the most current position of the addressed aircraft in relation to the other aircraft in the system.

APPENDIX C

DESCRIPTION OF ATC DEMONSTRATION TEST AIRCRAFT TERMINAL OPERATIONS, INTERFACES, AND SOFTWARE

TEST AIRCRAFT TERMINAL SYSTEM.

The FAA KC135 ATC demonstration test-aircraft terminal system consisted of a data processor (Varian 620/L), a cabin display/keyboard International Telephone and Telegraph (ITT) (model 3501 Asciscope), a logging device (paper tape punch), a hard copy device (Potter printer), a program read-in device (paper tape or link tape), a cockpit display unit (CDU) (Hamilton standards model B), an inertial navigation system (INS) and INS interface, a 400/60-Hz power converter, and a NAFEC audio patch panel. The system functionally satisfied the requirements of the ARINC 586 air-ground-air data link system.

A Hamilton Standards CDU was substituted for the CDU specified in ARINC 586. This CDU had some, but not all of the characteristics of the specified CDU. The onboard signaling standards detailed in section five of ARINC 586 were not implemented. Since off-the-shelf peripheral devices were used, it was far more cost-effective to use the computer manufacture's standard interfaces to the peripheral devices. The equipment complement for the ESA Comet and Rosman aircraft terminal system were similar with the following exception: The Rosman terminal did not require a 400/60-Hz power converter or INS, and the Comet terminal used an Omega navigation system in lieu of an INS.

Not all the components of the above system were ruggedized to airborne standards, but they proved very reliable in flight. The computer, as well as the Asciscope and paper tape system, were not ruggedized. The system was housed on two racks located in the aircraft cabin. One rack contained the computer processor, expansion chassis, Asciscope, paper tape reader and punch, and voice patch panel. In the KC135, a LINC tape unit was installed in place of the audio patch panel, which was relocated on the other rack that contained the power converter, printer, and audio equipment. The CDU and printer are ruggedized units designed to be installed in the aircraft cockpit, but this was not implemented in the ATC demonstration KC135 and Comet IV aircraft because of lack of available space.

DATA PROCESSOR. The purpose of the computer data processor was to accept digital signals from the satellite data channel, decode the message according to the ARINC 586 format, match the aircraft identification to either the live aircraft or one of six simulated aircraft, and display the message on the output device designated by the incoming message. The computer data processor accepted digital signals from the various input devices aboard the aircraft, formated the data, and sent it to the PLACE system for transmission to the ground terminal.

The computer data processor, which was a Varian 620-L-100 16-bit processor with 8k of 950 nanosecond memory, had the following input/output (I/O) controllers:

1. Universal asynchronous controller (USAC)--Varian model (620-82A-EIA interface),

2. Paper tape controller,

3. Dual synchronous controller for Bell 201 modems--Varian model (620-65B),

4. Buffered I/O controller--Varian model (620-80),

5. Priority interrupt module--Varian,

6. Digital input module--Varian,

7. Power failure/restart--Varian, and

8. INS interface card.

The processor software accepted and processed commands from the Asciscope keyboard, the CDU, and the PLACE data link modem output. It outputted data to the Asciscope display, the CDU, the printer, the PLACE data link modem input and the paper tape punch. It read data from the INS or Omega input, the altimeter input, and the Universal time (UT) clock input. For the devices that were under interrupt control, i.e., the Asciscope, data link modem, CDU, punch, and printer, interrupt handlers were provided. The input interrupt handled input data to an input buffer and set a flag for the device processor when a message was completely inputted. The output interrupt handled output data to the device, and set a flag when the output buffer was empty. Flow diagrams of the device processors are shown in figures C-1 through C-4. The device processors were responsible for reformatting and unpacking messages for each peripheral device, including the data link.

SIMULATOR SUBSYSTEM. The simulator subsystem was a software package that provided additional data link channel loading. It simulated position reports and data link messages for up to six simulated aircraft. The ATC demonstration had three simulated aircraft terminal systems, with a total of 18 simulated aircraft. Each simulated aircraft had up to 15 fixes (latitude, longitude) in its flight plan. When the ground system polled for a position report, the simulated aircraft reported the latitude and longitude of the addressed aircraft based on the time of its flight plan. Each aircraft table provided storage for the 15 fixes, airspeed, aircraft identity (ID), windspeed, wind direction, and altitude. A route table provided storage for 13 standard routes. To activate an aircraft, the pseudopilot typed in "AC, x," where "x" was the seven-character aircraft ID. The Asciscope then displayed the addressed rout number. The pseudopilot then selected 1 of the 13 prestored routes, and then selected a flight level, airspeed, and time of activation. This information was passed to the simulator, which calculated the time between fixes, and constructed a table of estimated time of arrival (ETA) at each fix. The pseudopilot could then enter windspeed and wind direction. The simulator modified the table of ETA's based on the new groundspeed. The pseudopilot could, at any time, amend each aircraft's flight plan, airspeed, windspeed, wind direction, or cancel aircraft. The simulator recalculated the table of ETA's for all fixes the aircraft had not passed.

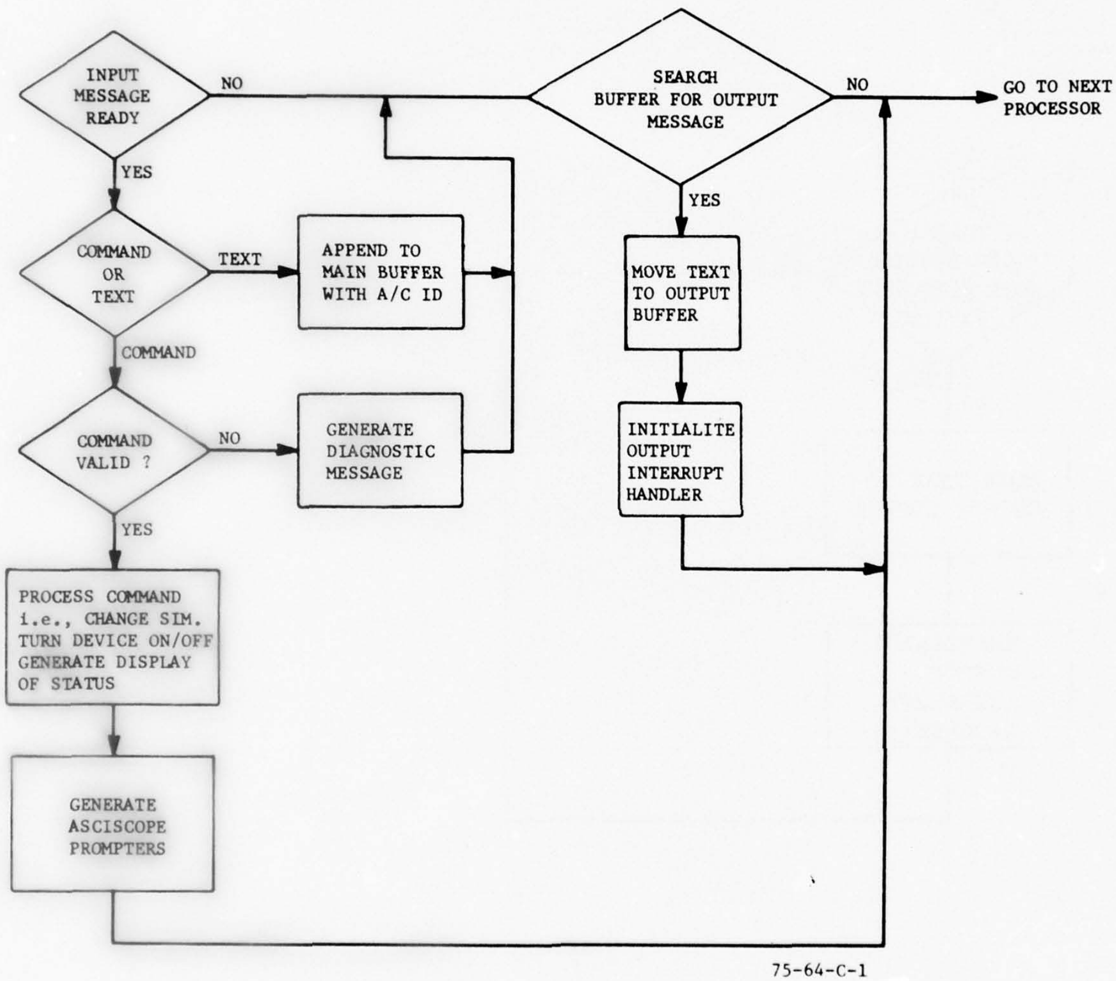


FIGURE C-1. ASCISCOPE PROCESSOR

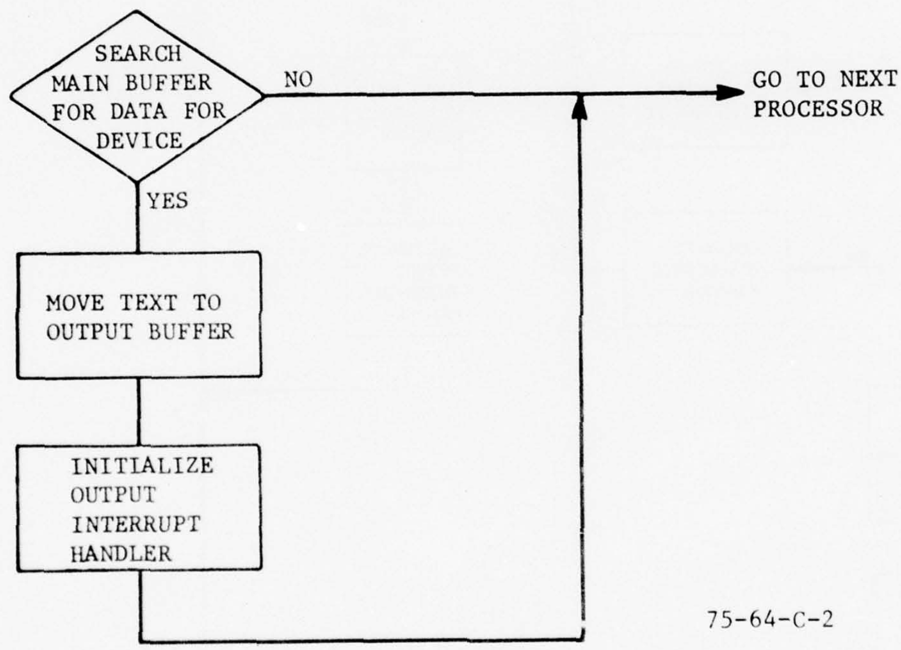


FIGURE C-2. PRINTER OR PAPER TAPE PUNCH PROCESSOR

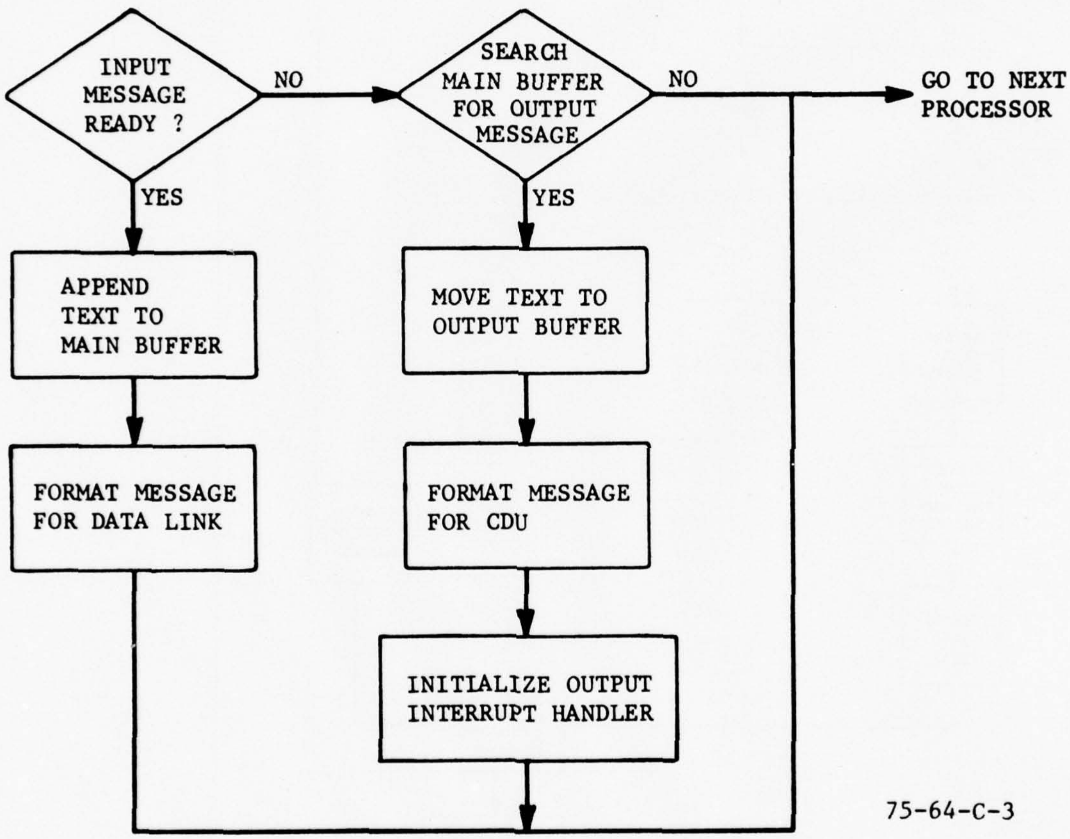


FIGURE C-3. COCKPIT DISPLAY UNIT PROCESSOR

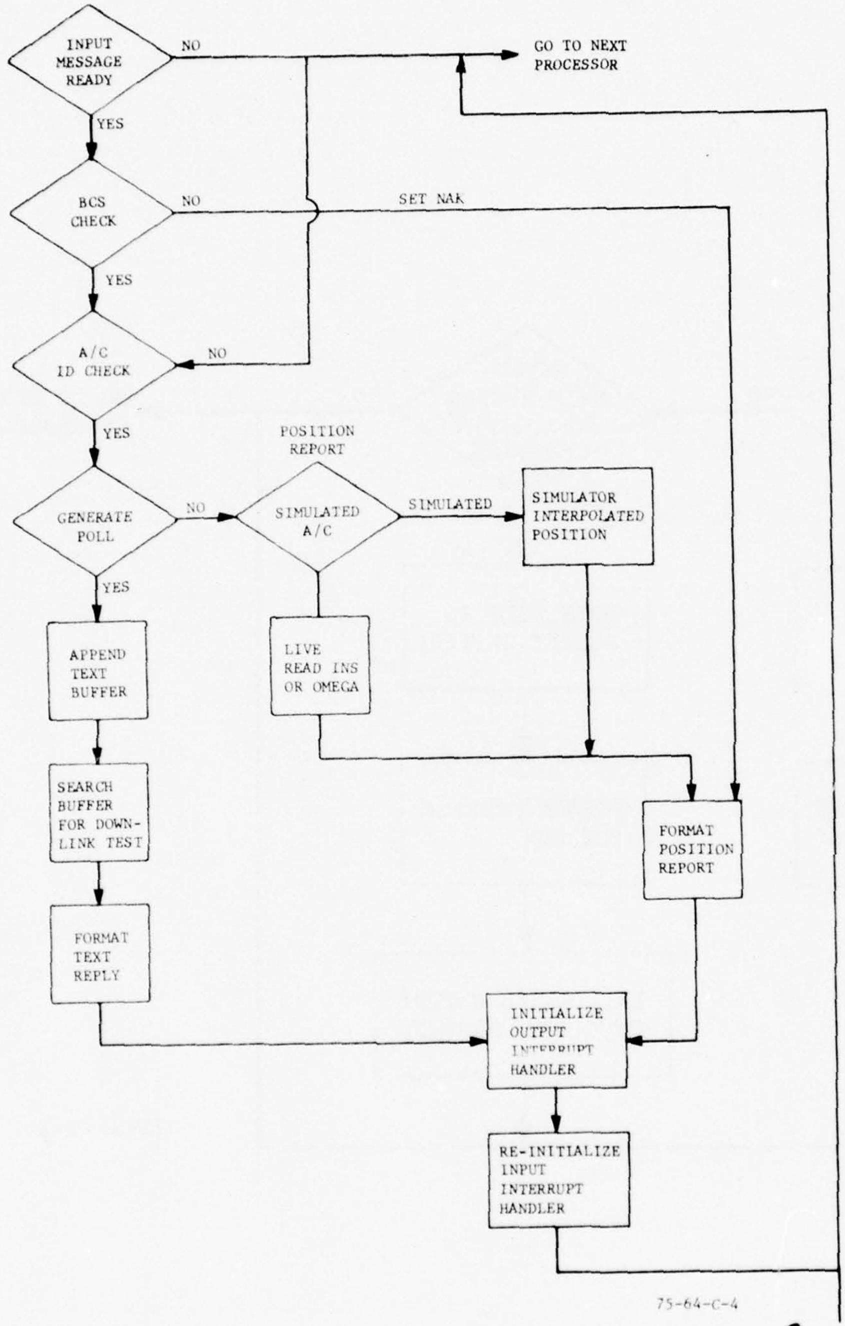


FIGURE C-4. DATA LINK PROCESSOR

When the aircraft was polled for a position report, the current time was compared with the table of ETA's, and a current position was interpolated. This report was formatted according to ARINC 586 and sent to the ground.

The operator could send a data link message for a simulated aircraft by typing the message and an aircraft ID on the Asciscope keyboard. If the aircraft ID matched a simulated aircraft ID, the message was formatted according to ARINC 586 and sent to the ground. Forward-messages and the associated aircraft ID's were displayed on the Asciscope. The position reports and data link messages appeared as live aircraft to the controller at the ground terminal. A flow diagram of the simulator is shown in figure C-5.

The following is an outline of the simulator subsystem software.

a. CAPACITY.

ROUTE TABLES. The route tables could accomodate 14 routes of 15 fixes each.

AIRCRAFT TABLES. The aircraft tables could accomodate six simulated aircraft, with each table having a capacity for 61 total words. Thirteen words were used for ASCII-represented data, four were for octal data, and 30 were for 15 fixes which constituted the aircraft flight plan. The remaining 15 words were used for a table of ETA's.

ID TABLES. The ID tables were used to store up to seven aircraft identifications, each having seven words.

INTERNAL TABLE. The internal table was used to transfer data between the various operating subroutines. Its length was 14 words.

PASS-ON TABLE. Between the executive and the simulator, all exchange of information was done in this 30-word table.

b. ADDRESSING.

Both the aircraft table and the route table were addressed by indexing. In the case of the route table, a particular route was accessed by multiplying the desired route number by 15 (number of fixes in a particular route) and using this as an address modifier in either the B or X registers.

The aircraft table was addressed by first calling the subroutine "SIDCH." The SIDCH subroutine matched the aircraft ID and assigned the aircraft a logical number between 0 and 5. This number was multiplied by the aircraft table length and was used as an address modifier in the B or X register to access the aircraft table.

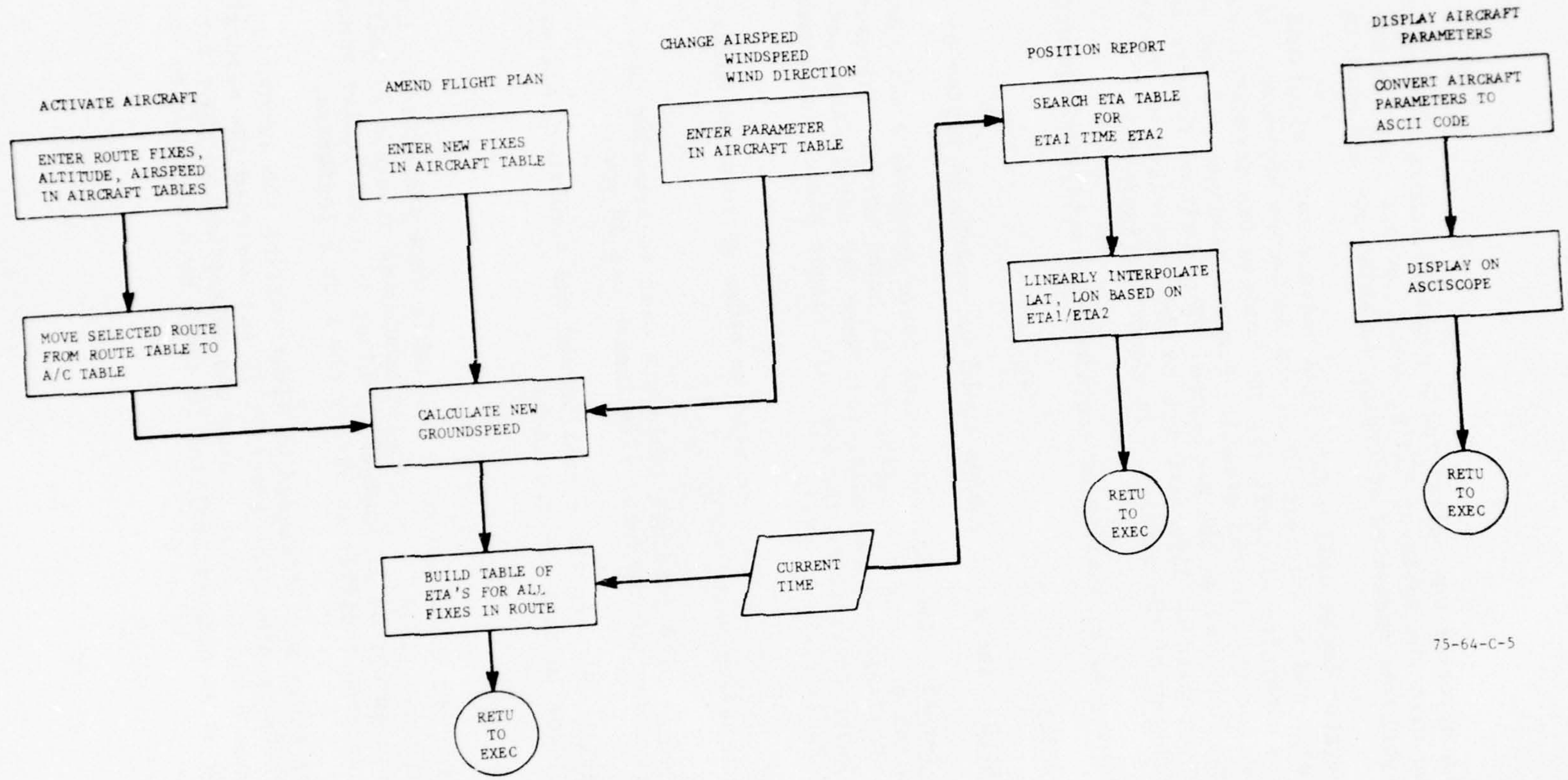


FIGURE C-5. SIMULATOR SUBSYSTEM FOR DATA LINK CHANNEL LOADING

c. PROGRAM FLOW.

The program was written as a series of subroutines. The functional subroutines were:

1. Activate aircraft (SACTI),
2. Change windspeed (SSWS),
3. Change wind direction (SCWS),
4. Change airspeed (SCWD),
5. Position report (SPOSI),
6. Display flight plan (SIFP),
7. Cancel aircraft (SCX), and
8. Amend flight plan (SAMD).

d. ACTIVATE AIRCRAFT (SACTI)

This subroutine accepted the following data in the pass-on table. The operation of the subroutine was as follows:

1. SACTI called SIDCH and verified that the aircraft specified in the pass-on had not already been activated.

2. SACTI called SLOT to find an open slot. SLOT checked the first word of each aircraft ID in the ID table for a cleared word. Since all zeros were not allowed in ASCII code, a cleared word was used to flag an empty slot.

3. SACTI then moved the aircraft data from the pass-on table to the aircraft table, using the addressing scheme described in "b".

4. SACTI then called SMOVRT, which moved the route from the route table to the aircraft table. An end-of-route flag was a latitude exactly equal to zero, and SMOVRT moved the fixes using the scheme in "b" until the flag was encountered.

5. SACTI then called SRECAL, after setting the X register equal to the location of the first fix in the aircraft's flight plan. The operation of SRECAL, described later, was an output table of estimated time of arrivals (ETA's) corresponding to each fix in the aircraft's flight plan.

CHANGE WINDSPEED, CHANGE WIND DIRECTION, CHANGE AIRSPEED. The operation of all of these subroutines was the same. The new parameter was stored in the aircraft table.

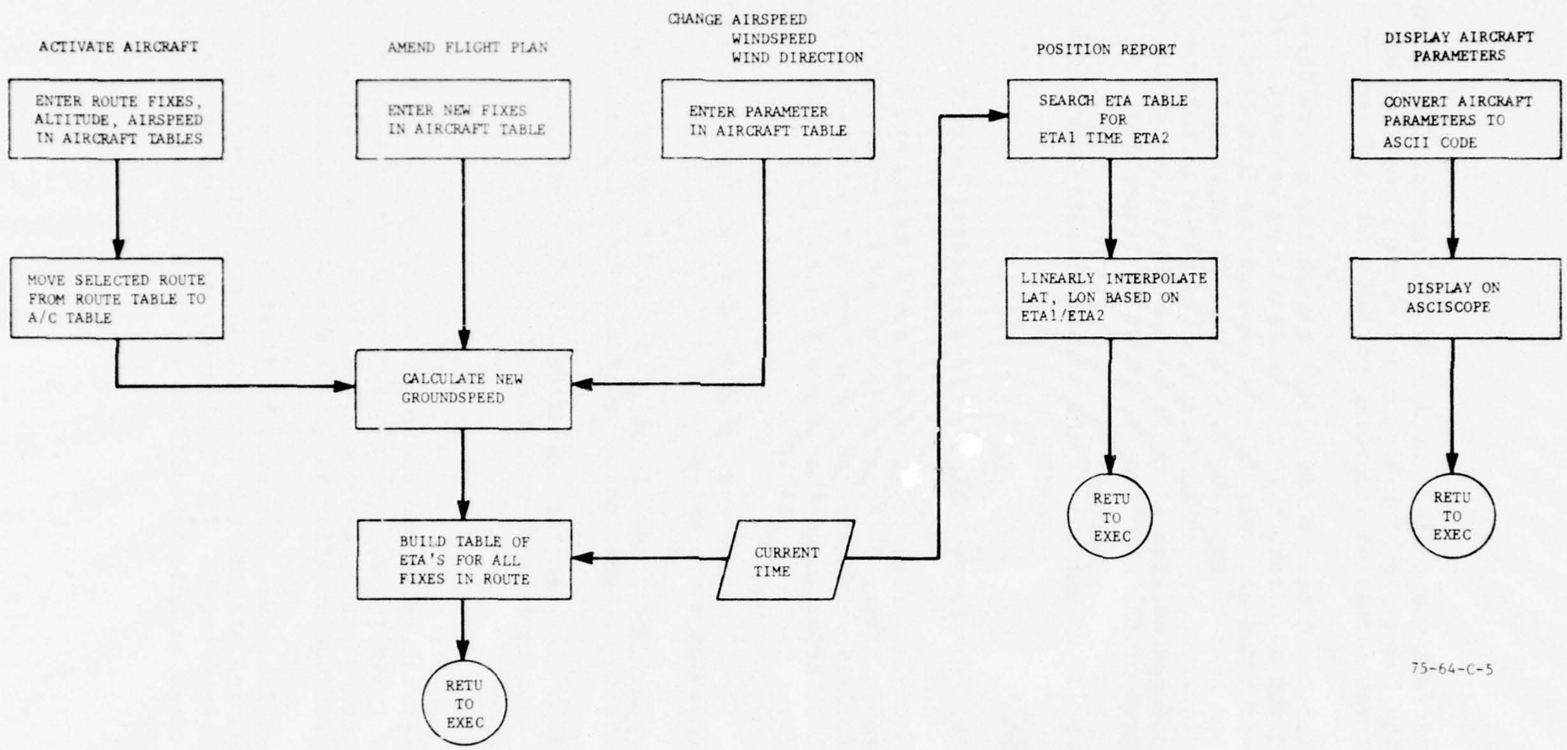


FIGURE C-5. SIMULATOR SUBSYSTEM FOR DATA LINK CHANNEL LOADING

SFLFX was called, which compared the current time with table of ETS's until it found the number of the fix the aircraft was flying toward. This number was added to the location of the first fix in the aircraft flight plan and this was stored in the X register. The subroutine SRECAL was then called. This subroutine modified all ETA's from the current time until the end of the aircraft flight plan based on the new parameter.

POSITION REPORT (SPOSI). SPOSI called SIDCH to match the aircraft ID. It then called STRM, which compared the current time with the ETA over the last fix in the aircraft flight plan to see if the aircraft was terminated yet. SPOSI then called SFLFX (the operation of which was described in "d") SPOSI then interpolated the latitude and longitude of the aircraft based on the current time and the ETA's of the fix the aircraft had departed and the one it was flying towards. SPOSI then converted the latitude and longitude to ASCII and assembled a message.

AMENDING A FLIGHT PLAN (SAMD). The program called SIPCH to match the aircraft ID. It then called SFLFX to find the number of the fix the aircraft was flying toward. This number was compared with the number of the fix to be amended. If the fix to be amended was a future fix, it was stored in the aircraft table and SRECAL was called after setting the X register equal to the location of the amended fix. SRECAL then calculated new ETA's from the amended fix to the end of the aircraft flight plan. If, however, the aircraft was flying toward the fix to be amended, the fix the aircraft had departed was replaced by the current position of the aircraft. The amended fix was stored as the next fix, and SRECAL was called, which recalculated new ETA's from the current position to the end of the aircrafts flight plan.

CANCELLING AIRCRAFT (SCX). After calling SIDCH to match the aircraft ID, the program cleared the aircraft ID, replacing all seven words by zero.

DISPLAYING A FLIGHT PLAN SIFP. The program read ASCII data from the aircraft table using the indexing scheme described in section "b". Since the route fixes were stored in binary notation, in the interest of saving core, these parameters were converted to ASCII degrees and minutes when a display was called for. When the subroutine SIFP had completed a line to be outputted, it called the executive routine INTF.

SRECAL. This subroutine built a table of ETA's over each fix of the aircraft flight plan. Note that this subroutine did not always recalculate new ETA's from the first fix in the aircraft flight plan, but rather started recalculating at whatever fix was specified by the calling program.

SRECAL read the fixes out of the aircraft table and called DIST, which computed the distance between the fixes. DIST averaged the latitudes involved in the leg of the flight, then looked up the cosine of this average using indirect addressing in a cosine lookup table. This cosine was multiplied by difference in longitude to form the longitude. The $(\text{Long})^2 + (\text{Lat})^2$ was computed. The square root of this was found by using Newton's method, with two iterations. The initial value was either the longitude or the latitude, whichever was greater. This formed SDIS, the distance between fixes.

c. PROGRAM FLOW.

The program was written as a series of subroutines. The functional subroutines were:

1. Activate aircraft (SACTI),

2. Change windspeed (SSWS),

3. Change wind direction (SCWS),

4. Change airspeed (SCWD),

5. Position report (SPOSI),

6. Display flight plan (SIFP),

7. Cancel aircraft (SCX), and

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5. SACTI then called SRECAL, after setting the X register equal to the location of the first fix in the aircraft's flight plan. The operation of SRECAL, described later, was an output table of estimated time of arrivals (ETA's) corresponding to each fix in the aircraft's flight plan.

CHANGE WINDSPEED, CHANGE WIND DIRECTION, CHANGE AIRSPEED. The operation of all of these subroutines was the same. The new parameter was stored in the aircraft table.

The airspeed, windspeed, and wind direction were then used to compute a groundspeed. The aircraft track angle (the angle the aircraft track makes with north) was first computed. This was done by computing COS^{-1} longitude. The COS^{-1} was found by using the cosine lookup table in reverse. The difference between this angle and the wind direction angle was then computed (after attention to the sign of the results). The cosine of this difference angle was taken, and the result multiplied by the windspeed. This result was the projection of the wind vector onto the aircraft's velocity vector and was the component of the wind affecting the groundspeed of the aircraft. The airspeed was added to this result algebraically to form the aircraft groundspeed.

The groundspeed and distance were then used (after correcting for the difference in units) to compute the ETA over the next fix.

ITT 3501 ASCISCOPE DISPLAY.

The ITT 3501 Asciscope display terminal was a 12-line by 80-character CRT terminal that served as the cabin display/keyboard. The Asciscope can be used in the block transfer mode, but in the ATC demonstration, it was used in the full-duplex mode, which made all software written for the Ascicsope compatible with a teletype. The teletype was convenient during the software development phase for hard copy. At the interrupt handler level, the Asciscope software provided for simple editing features, such as line deletion and entry deletion. At the Asciscipe processor level, the software provided for system configuration console commands, simulator subsystem directives, text message entry and display, and system status requests. The system configuration console commands consisted of the peripheral ON/OFF control. These commands did not electrically turn the device ON or OFF, but allowed the system software to ignore these peripherals. Thus, a faulty peripheral device could not "hang up" the system. ON/OFF control was provided for the printer, the paper tape punch, the INS, and the PLACE data link modem input. In addition, the system configuration console commands allowed the airborne subsystem clock to be slaved to the ground or run autonomously. A command could cancel the data in the main buffer if it became overloaded.

The simulator subsystem directives allowed the pseudopilot (console operator) to "fly" the simulated aircraft. Directives were provided to activate aircraft, amend flight plans, change airspeeds and flight level, enter windspeed and direction, cancel aircraft, and display flight plans. Using these commands, the console operator could respond to an ATC's request. These commands initiated recalculations by the simulator software. The text message entry commands allowed text messages entered on the Asciscope keyboard to be associated with a particular simulated or live aircraft. In addition, the entered text messages could be assigned a priority and a designation. Two designations were provided in the ATC demonstration; ATC messages, and demonstration and other-purpose messages. The system status request commands provided the operator with a status display giving the ON/OFF status of all peripherals and the currect system time.

The Asciscope was interfaced to the computer via a single standard interface card, the Universial Asynchronous Controller (USAC). The USAC used the device address normally assigned to the teletype controller. The input or output to the Asciscope is in an eight-bit character parallel fashion. The USAC provided the conversion of the parallel signals to serial for interface to the Asciscope. The signals were EIA RS-232 compatible, and the baud rate was 122 b/s.

PAPER TAPE SYSTEM.

The paper tape system consisted of a 150-character-per-second (c/s) tape reader and a 75-c/s punch. The reader was used for program loading, but served no online purpose during the conduct of the ATC demonstration. The punch was used for data logging. To load the operational software using paper tape, the operator had to enter the bootstrap from the front panel, load in binary load and dump (BLD), and use BLD to load in the two rolls of operational software. Forward-link and return-link text messages as well as position reports were logged on the punch. The time of reception or transmission of each forward-link or return-link message was logged on the same line as the message. The first seven characters in each line of the log were available for entry of the date. A log comment command from the Asciscope keyboard enabled the operator to enter comments on the log. The paper tape system was interfaced to the computer with a standard paper tape controller. Transfer to and from the computer was eight-bit parallel. All logging was done using ASCII code. This enabled one to obtain a hard copy by simply running the tape through and offline teletype.

HIGH-SPEED PRINTER. The Potter high-speed printer, model 3609 was the hard copy unit used for the test aircraft terminal system. ASCII data were printed out at a speed of 150 lines per minute in 33 columns on 4-inch-wide paper. Two copies were printed, with the record copy rolled inside. The printer printed forward-link messages and all entries made on the Asciscope keyboard. Both of these functions were valuable, since the Asciscope had only 12 lines. Since messages were displayed rapidly on the Asciscope, lines were often lost off the top of the display before they could be read and understood. The Potter printer was interfaced using the buffered I/O (BIO) card. The BIO card provided 16 bits of parallel input and output. The eight least significant bits of the BIO were used to output to the printer in a serial-by-character, parallel-by-bit fashion. The Potter printer saved the 6-bit ASCII characters until a 33-bit register was full, and then printed the entire line. An external data strobe shifted in each six-bit character. The printer recognized a line-full condition and automatically generated a line feed. If the line was less than 33 characters, the program contained an octal 35 code that caused a line feed.

MAGNETIC TAPE SYSTEM. The LINC magnetic tape system, manufactured by Computer Operations, was substituted at the KC135 test aircraft terminal for the paper tape reader as the means for loading the operational programs. (LINC tape uses a format different from industry standard nine-track or seven-track tape. Each LINC tape is preformatted into fixed-length blocks, each with a permanent block number). The software supplied with the LINC tape included a version

of the Varian AID debugging package which enabled reading programs into core in about 10 seconds. This contrasted sharply with the 15 minutes or more necessary to load the system with the paper tape reader. Although the LINC tape was capable of logging data, the paper punch was retained as the logging device at this terminal, to facilitate hard copy with an offline teletype.

COCKPIT DISPLAY UNIT.

The cockpit display unit (CDU) provided the capability for visual display of short-length ATC messages and initiating a selected number of ATC messages or responses. Figure C-6 shows the front panel of the CDU. The IDENT readout displayed four alpha characters and one numeric. The VALUE readout displayed four numeric characters and sign bit.

The keyboard consisted of a 10-button keypack with one number and three letters on each key. In addition, discrete function keys such as WILCO, UNABLE, FUNCT I, FUNCT II, and INSERT were provided. There were many possibilities with such a keyboard layout, but most of them were discarded as too complex in operation.

A simplified, though rigidly formatted technique was chosen for the ATC demonstrations. A type 1 message consisted of four letters. A type 2 message consisted of two letters and three numbers. The pseudopilot selected the buttons bearing the letters in the message. Only one button was pushed for each letter. If the letter combination did not match one of the prestored letter combinations, "NO GO" appeared on the display; otherwise, the letter combination selected was displayed. In a type 2 message, any combination of numbers could be selected to enter the numeric data. The repertoire of messages could have been expanded or altered; however, no provisions were made to send return-link messages that had not been previously agreed on. Any combination of characters could be displayed as long as they fit the format of a type 1 or type 2 message. The following are samples of type 1 and type 2 messages for forward-link and return-link applications:

Return Link

Type 1:	RQVC	Request Voice Channel
	HIJK	Hijack
	EMEQ	Emergency
	RQDL	Request Data Link Channel
Type 2:	ET###	Estimated Time to Next Fix ###
	LF###	Leaving Flight Level ###
	MF###	Maintaining Flight Level ###
	RF###	Request Flight Level ###
	RH###	Request Hold at Next Fix for ###

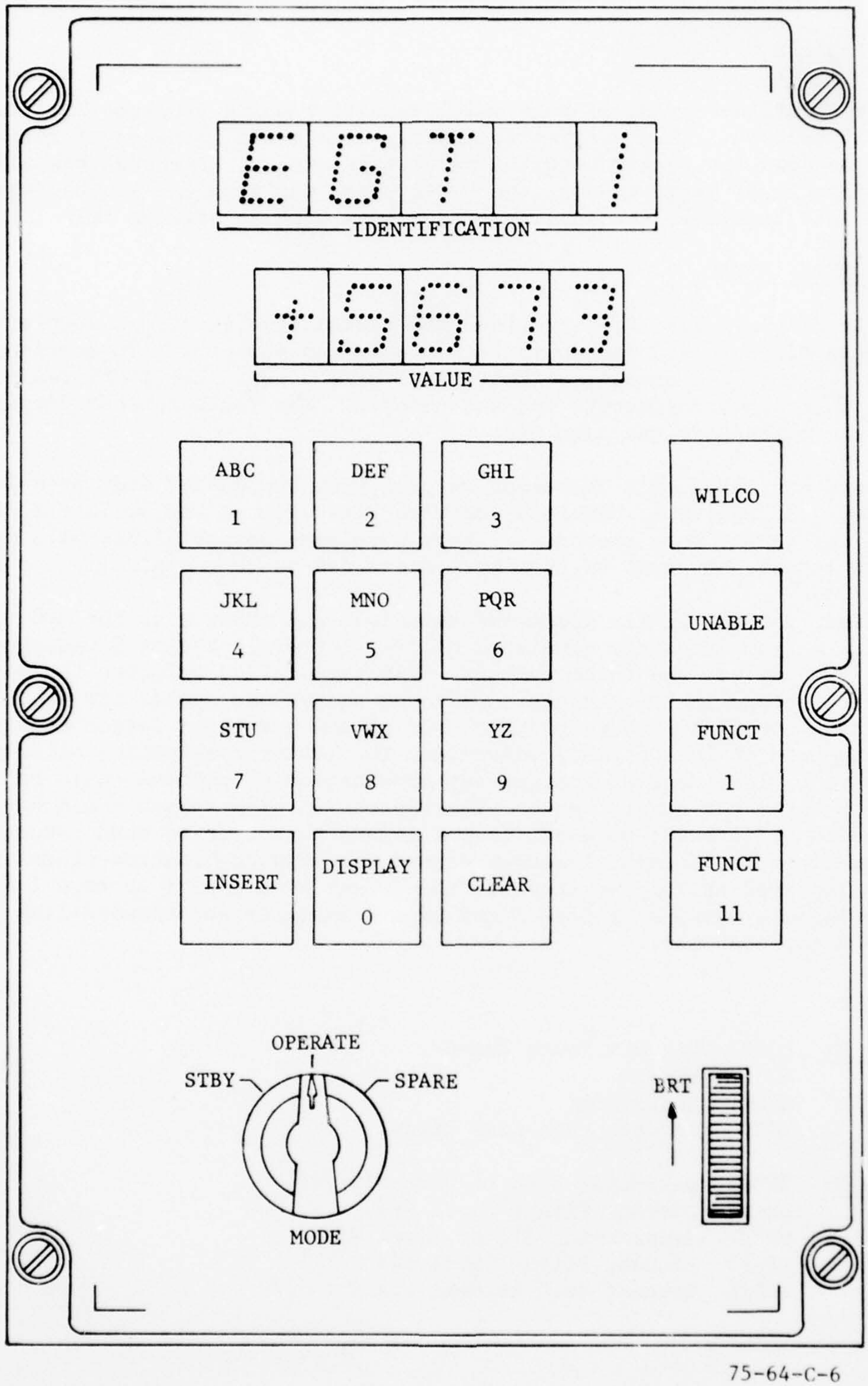


FIGURE C-6. VIEW OF COCKPIT DISPLAY UNIT FRONT PANEL

Forward Link

Type 1:	RRFL	Report Reaching Flight Level
	RLFL	Report Leaving Flight Level
	TEST	Test Message
	REPT	Say Last Message Again
Type 2:	CF###	Climb to Flight Level ###
	DF###	Descent to Flight Level ###
	HD###	Turn to Heading ###
	SP###	Change Speed ###
	DL###	Change to Data Link Channel ###
	VC###	Change to Voice Channel ###
	HH###	Hold for # Hours and ## Minutes

The CDU was interfaced to the computer using one half of the 620-65B synchronous modem controller. This card, although a standard module, was modified extensively to provide a 32-bit shift register on input instead of the eight-bit register normally provided. The transmission of data between the 620-65B and the CDU was done using a 3072-Hz clock, provided by the 620-65B. When 32 bits of data from the CDU were ready to be input to the computer, the 620-56B notified the computer using a predesignated interrupt line. To output to the CDU, the 620-65B generated an interrupt through a second predesignated interrupt line. Each time it was ready to accept an eight-bit data byte, it shifted this byte to the CDU for display. A total of 14 data bytes were necessary to generate a complete CDU display.

The format for output data to the CDU is shown in figure C-7. The first eight bytes (four words) were used to provide data to the four alpha displays. Each display consisted of 16 segments in the pattern shown. Each bit in the 16-bit word lighted one display segment. The software mapped ASCII keyboard codes that were received on the data link into the 16-bit display words to provide a full alphabet. The sixth and seventh words provided data to the lower numeric displays in binary-coded decimal (BCD) format. To generate a display, the program entered the display data in the 14-byte display file and outputted these bytes to the 620-65B under interrupt control.

The format for data input from the CDU is shown in figure C-8. An interrupt indicated to the program that data were ready. The program then responded by two consecutive inputs from the 620-65B controller. The 620-65B was modified to provide the first 16 bits on the first input instruction and the second 16 bits on the second input instruction. As can be seen from the format, four bits in a BGD code for each data button pushed were transmitted, as well as a code for the button used to enter the data.

When the two words (32 bits) of data were inputted, the program examined the discrete codes (bit positions 5 through 12 of the second word). If the discrete codes indicated that the "INSERT" button was used to enter the data, it matched the eight-bit code representing the BCD codes for the first two buttons

DATA RECEPTION
(From 620/L to CDU)

BIT	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
FIRST WORD	2^3	2^2	2^1	2^0	1	0	0	0	0	0	0	0	0	0	0	0

NUMERIC 0

SECOND

EACH BIT LIGHTS ONE SEGMENT ON THE DISPLAY

THIRD

FOURTH

(Refer to display example)

FIFTH

SIXTH 2^2 2^1 2^0 2^3 2^2 2^1 2^0 2^3 2^2 2^1 2^0 ∅ ∅ ∅ ∅ ∅

LSB

:

SEVENTH 1 1 1 1 1 1 1 1 A B (SIGN) 2^3 2^2 2^1 2^0 2^3 (MSB)

∅ - represents do not care

A	B	
0	0	+
0	1	-
1	0	1
1	1	Blank

ALPHA DISPLAY EXAMPLE

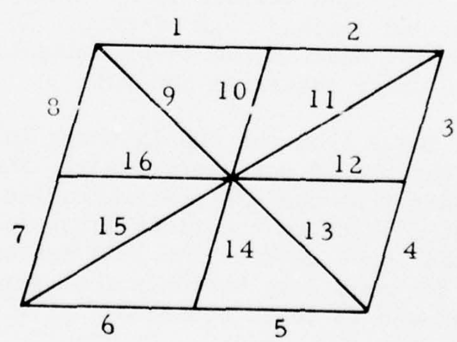


FIGURE C-7. PROGRAM FORMAT FOR OUTPUT DATA TO THE COCKPIT DISPLAY UNIT

DATA TRANSMISSION
(From CDU to 620/L)

BIT	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
FIRST WORD	2^3	2^2	2^1	2^0	2^3	2^2	2^1	2^0	2^3	2^2	2^1	2^0	2^3	2^2	2^1	2^0
	Second Digit				Third Digit				Fourth Digit				Fifth Digit			
SECOND WORD	Ø	Ø	Ø	Ø	H	G	F	E	D	C	B	A	2^3	2^2	2^1	2^0
													First Digit			

Computer not busy $\overline{\text{(busy)}}$ signal

Ø - represents do no care

TRANSMISSION BUTTON CODE

H	G	F	E	D	C	B	A	
1	0	1	1	1	1	0	1	INSERT
1	0	1	1	1	0	1	0	FUNCTION 2
1	0	1	1	0	1	1	0	DISPLAY
1	1	1	0	1	1	1	0	UNABLE
1	1	0	1	1	1	1	0	WILCO
1	0	1	1	1	1	1	0	FUNCTION 1

FIGURE C-8. PROGRAM FOR DATA INPUT FROM THE COCKPIT DISPLAY UNIT

pushed against a table of fixed-format messages. For example, if the second and seventh buttons were pushed, the code would be 0010 0111. This would match up with the fixed-format message "ET" (estimated time), which would be mapped into display characters and shown on the display. The program would then interpret the next three buttons pushed as numerical data, which appeared in the VALUE display. The FUNCT II button was used to enter the three numbers, and the entire message was converted to ASCII and sent to the ground station. If the message was of the type I, which required no numerical data, only the IDENT line of the display was sent.

POWER FAILURE/RESTART.

The ATC demonstration test aircraft terminal data link system used a power failure/restart (PFR) which was an option for the 620/L computer. Sensing circuits on the PFR card caused a program interrupt when the line voltage dropped below 105 volts. This interrupt vectored the program to a routine which provided for an orderly shutdown of the system. This routine could be up to 160 milliseconds in length. When the line voltage returned to normal, an interrupt was generated which vectored the program to a startup procedure. One typical application of the power failure interrupt was to save all volatile registers and the program counter in core storage. When the power was restored, the power-up routine restored all registers and the program counter and resumed the program that was interrupted.

However, this type of treatment is not directly applicable to a real time, on-line program. If the power is OFF for any length of time, the data link interrupts cannot be supported. Resuming the program at the point the power failed would result in half-full buffers and garbled messages. The entire software package might fail because certain key characters in the data link message might be missed.

Therefore, the approach chosen for the ATC demonstration application was to simply execute a halt on power-down. On power-up, the program vectored to a routine which reinitialized the data link and other critical input/output, cleared data buffers, and resumed processing. Any processing that was being done at the time the power failure occurred was not completed. All processing done after the interrupt was the result of input/output that occurred after the power was restored.

DATA LINK OPERATION.

The ATC demonstration data link operation was similar at the three test aircraft terminals. Synchronous data were transmitted at a 1200 b/s rate. In the K135 aircraft, the demodulator clock was used to shift data into one-half of the 620-65B modem controller. The other half of this controller was used for the CDU. A clock was supplied by the 620-65B to shift data from the computer into the data link. A request-to-send signal was raised while data were being outputted to the PLACE data link modem. This signal caused the PLACE modem to modulate the carrier. The signal was removed after each message was transmitted, so that the other test aircraft terminals (ESA Comet, and Rosman simulated aircraft) could transmit without interference.

The installation at Rosman was identical to the KC135. The installation on the Comet was the same except that the request-to-send was gated with the clock. This cut off the clock on the Comet between transmissions, because the characteristics of the modem aboard the Comet would cause modulation at another frequency if this were not done. The 620-65B synchronous modem controller was used to interface the computer with the PLACE data link modem. The 620-65B was modified to convert the differential transister/transister logic (TTL) signals to the EIA RS-232 signals required by the 620-65B.

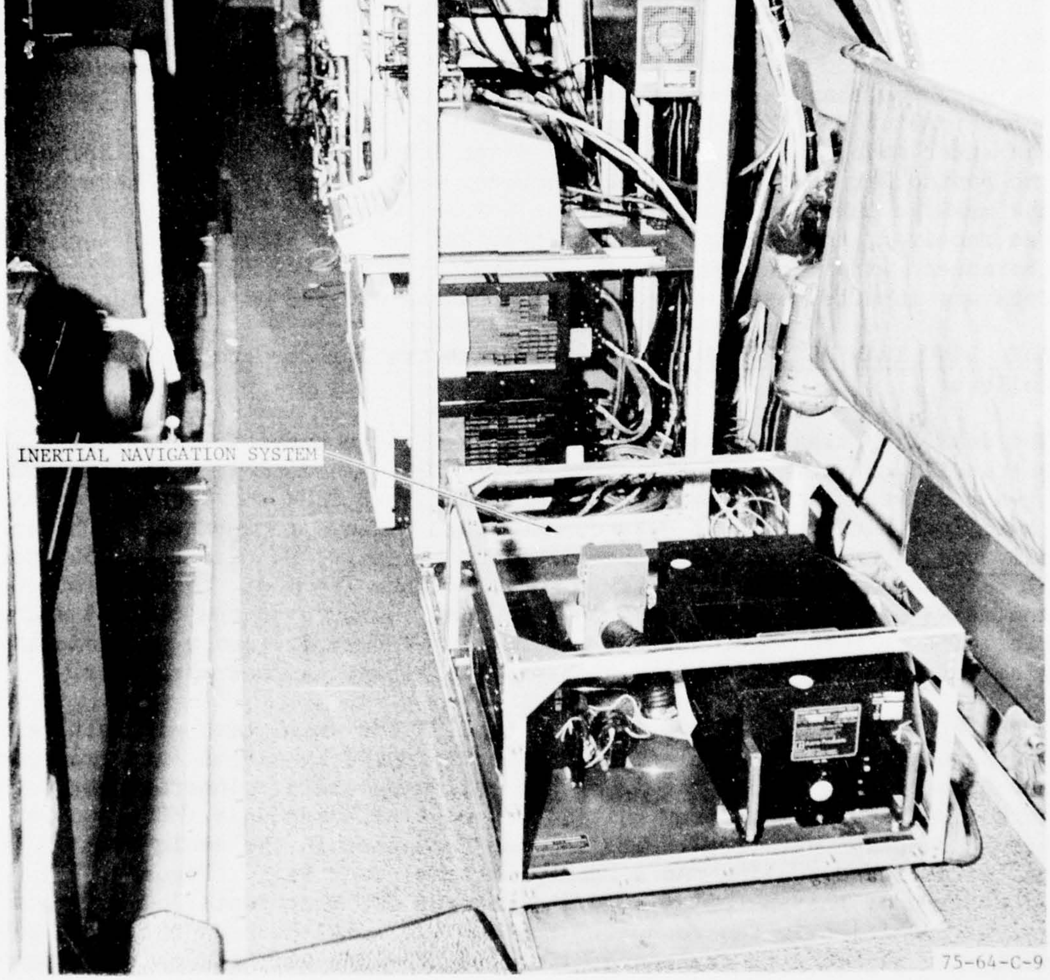
DATA LINK RECEIVE PROGRAM, The data link receive program execution was as follows:

The 620-65B modem controller required that the sync character recognition be done by software. Each time a bit was shifted in by the demodulator clock, an interrupt occurred on a predesignated line. The eight-bit word in the register was then examined to see if it matched the code 226 used in the ATC demonstration for character sync. If it did, the 620-65B was switched to character mode, and a second code 226 was looked for. If this also matched, the controller continued in the character mode, bringing each character of the message into the data link input buffer. When an end-of-text, (ETX) code was received, the message was complete, and the two block check sequence (BCS) characters were inputted, and the controller was returned to search mode. Data was inputted eight bits at a time on the 620-65B modem controller.

DATA LINK TRANSMIT PROGRAM. The data link transmit program execution was as follows:

The data link transmit program first raised the request to send. Then, it outputted 150 characters of all zeros to the 1200-b/s data link channel, which, when received at the ground PLACE equipment, provided the required signal for phase lockup of the PLACE data demodulator. Then, it ouputted 50 characters of all ones for PLACE modem synchronization. Finally, it outputted 150 characters of code 210 for telephone circuit modem synchronization. Then, it outputted the message string and request to send. All outputs to the 620-65B modem controller were done eight bits at a time. An interrupt from a predesignated line indicated the controller was ready to accept another character.

INERTIAL NAVIGATION SYSTEM. The INS used in the KC135 test aircraft terminal was a palletized ARINC-561-type INS, manufactured by Litton Aero Products. It was a model LTN-51, consisting of the following units: Inertial navigation unit (INU), control display unit (CDU), mode selector unit (MSU), and a remote display unit (RDU). The INU was installed in the cabin area. The pallet included cooling and a backup battery power unit. Figure C-9 is a photograph of the installation. The MSU and CDU were installed at the navigator's position in the cockpit. The RDU was located on an ancillary equipment rack adjacent to the pseudopilot. A CPU-43/A air data computer provided true airspeed data in synchro form to the INU for use in computation of windspeed and direction. The primary function of the INS was to provide automatic



JRE C-9. PALLETIZED INTERTIAL NAVIGATION SYSTEM INSTALLATION--KC135 AIRCRAFT

aircraft position data to the ATC demonstration 620/L data link computer. The serial binary coded decimal (BCD) output from the inertial system, consisting of data, clock, and synchronization signals, was provided to the 620 computer data processor. The data processor selected inertial output data using a label-match technique to obtain the required parameters of present position latitude and longitude, windspeed, and wind direction. The INS interface consisted of an INS interface card, a buffered I/O card, and a digital input module.

The INS interface card provided a serial-to-parallel interface for the ARINC-561-formatted INS data. The card consisted of a 32-bit shift register, an eight-bit storage register for the desired label to be matched, and label-match recognition logic. The INS data was clocked into the 32-bit shift register by the INS clock. When a sync pulse was present, the data from the shift register was strobed into one side of the eight-bit label-match register. The other side of the eight-bit register was provided by the BIO card. When the labels matched, a module 24 counter was initiated. When this counter was completed, the data was strobed from the 32-bit shift register to the digital input module, which provided a 32-bit parallel interface for the INS data. The BIO card provided a means for the program to output the desired label for INS data. The eight most significant bits of the BIO were tied to one side of the eight-bit label-match register in the INS interface card.

The digitel input monitor (DIM) was used in conjunction with a multiplexer to select one 16-bit port out of the eight 16-bit ports provided. The 620/L program obtained the INS position and wind parameters by outputting the label (i.e., latitude is label 20, longitude label 220) to the BIO. It then waited for a "sense time" signal indicating that the parameter was available to be input to the DIM. It then input the parameter, converted it from BCD to ASCII and sent the next parameter label to the BIO.

OMEGA NAVIGATION SYSTEM. The ESA Comet Omega navigation system outputted aircraft position data in parallel 1-2-4-8 BCD form. The Omega parallel data was interfaced to the DIM. A 16-bit input register was used to input the four BCD latitude characters. Longitude was input on a second 16-bit register. Hundreds of degrees longitude were not input. The Omega system provided a strobe at 1-minute intervals to update the data in the DIM. The 620/L program read the position information directly from the DIM and converted it to ASCII characters for insertion into the ARINC 586 data link format. Since altitude was not available in digital form on the Comet, this parameter was stored as a constant in the program.

Altitude data for the ATC demonstration KC135 test aircraft terminal data link was obtained by paralleling an existing digitally encoded altitude input to the aircraft's transponder unit. The altimeter unit was a Smith Industries Limited, type 3B, series 1100. The altitude code was an 11-bit, parallel code in which a ground represents "data" or logic 1, and an open or high resistance represents "no data" or logic 0. Coding details of altitude versus pulse position assignment can be found in ICAO annex 10, volume I, dated July 1972.

Altitude-coded data were continuously available at the 620/L computer interface input. The interface conditioned and encoded these data to a binary format which was inputted to the processor via the DIM. The processor reformatted these data to an ASCII code in ARINC 586 format. These data were buffered for transmission to the ground as part of the response to an aircraft position poll.

AUDIO PATCH PANEL. The demonstration audio patch panel provided jacks for the pseudopilot microphone, headset, and push-to-talk (PTT) switch. A switch located above the jacks permitted switching of the microphone and PTT functions to the panel jacks or to the pilot station in the cockpit. The headsets were not switched so that continuous monitoring of the receive voice was provided at both locations. Status lights on the panel and at the pilot station indicated which location the microphone was switched to. Two additional headset jacks on an auxiliary panel provided additional monitoring of received voice at the pseudopilots position. Each headset had individual level controls. The pseudopilot had access to the aircraft intercommunication system for communication with the flight crew.

Included on the audio patch panel was a horizontal row of nine lights indicating the status of the PLACE satellite communications system. These lights were remote displays of indicators installed on the PLACE modem unit which were at a different location in the aircraft. Six lights (V1. V2, V3, D1, D2, and D3) indicated the "in-use" (lighted) or available (extinguished) conditions of the three voice and three data channels of the PLACE system. These lights were controlled by digital signals initiated by the PLACE ground equipment and transmitted to the aircraft via the PLACE surveillance and ranging (S&R) channel. Decoding of these signals and generation of status light actuation signals was performed within the PLACE airborne modem. The remaining three lights were actuated by sensing circuitry within the PLACE airborne equipment and indicated the following:

Demod Lock (DL)--when illuminated, indicated that the coherent demodulator-phase locked loop had acquired lock.

Epoch Lock (ELO)--lighted when the epoch synchronization was decoded correctly on the PLACE S&R channel.

Air Emergency (AE)-- (not used in the demonstrations) is illuminated on a declared air-emergency condition.

The above-described audio patch panel was used at the three test aircraft terminals; however, all of the functions were not utilized at the Comet IV and Rosman simulated aircraft terminals. The PLACE status lamp function was not applicable at the Comet because a different type of L-band satellite communications equipment was provided. The pilot remote access function was not required for the simulated aircraft at the Rosman terminal.

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